LECTURES
DELIVERED IN THE
INDUSTRIAL AND
TECHNOLOGICAL MUSEUM.

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INDUSTRIAL AND TECHNOLOGICAL MUSEUM.

LECTURES

DELIVERED IN THE

LECTURE ROOM OF THE MUSEUM

DURING THE

SPRING SESSION OF 1870.

PUBLISHED UNDER THE DIRECTION OF THE COMMITTEE,

WITH

AN INTRODUCTION BY THE SECRETARY.

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INTRODUCTION.

THERE ought to be no necessity to set forth in a young community the advantages of Technological Instruction. On the Continent of Europe it has long ago been admitted that such a system of instruction is most desirable; and in England—thanks to the liberality of certain advanced thinkers—it has of late made rapid progress.* I however believe that, were many asked to explain what they understood by a system of Technological Instruction, it would be found that their notions on the subject were hazy in the extreme. Technology is known to be something indefinitely connected with science and art; but where that connection begins or ends, and how the artistic or scientific knowledge gained under the proposed scheme is to be applied to the practical business of life, is most imperfectly understood. The word "Technology" has been objected to by many because of its "hardness." I think that the objection will be found to arise more properly from its "newness." When the meaning of the term is once clearly explained, the difficulty removes itself, and the working man —always cherishing a natural horror of fine words—will

* Sir Joseph Whitworth has given £100,000 for this purpose. In America Technology has made great and rapid strides, as may be seen by the following:—The Technological Institute of Boston has recently received the following munificent contributions—Mr. Huntingdon, £10,000; Mr. Thayre, £5000; Mr. Mason, £4000; Mr. Hayward, £4000; and Dr. Walker, no less than £40,000.

understand that the new movement has been set on foot for the purpose of making difficult things plain to him—not plain things difficult.

Technology means, simply, that branch of knowledge which teaches the application of science and art to industry, and Technological instruction, instead of being a terrible course of study, bristling with thorny thickets of intricate specialities and arid with sandy wastes of dryest learning, is but a plain setting-forth of the principles of science and art, and an explanation of the method by which the application of these principles has brought about practical results. The Technologically-instructed workman will be no longer the "hand," pouring this dye stuff into that trough, or mixing this compound of red stuff with that compound of blue stuff, simply because it is the custom in his factory to so mix and pour; but he will be the intelligent "head," understanding that the chemical changes, or the mechanical effects which he produces are not the result of accident or custom, but arrive by reason of the operation of certain chemical and mechanical laws, *which laws he fully comprehends, and can apply to the explanation of other trade processes.* And herein lies the difference which is not distinguished by many persons. Technological instruction does not aim at the mere furtherance of manipulative skill—that a stonemason shall become merely the best stonemason in the world—but it desires that the working man shall be an intelligent being, able to "substitute the sweat of the brow by the thought of the brain"—that the stonemason shall join with his manipulative skill an acquired capacity for understanding the principles, and possibly of improving upon the practice, of the work in which he is engaged. The old system of confining the exercise of an artisan's intellect to the sole consideration of that trade whereby he earns his

bread is, indeed, antagonistic to Technology. To limit education to mere instruction in manipulative skill is but to limit the sphere of usefulness of the person instructed. "If George "Stephenson," says Professor Lyon Playfair, "had only ac-"quired the manipulative skill of shovelling coals adroitly "into the furnace when he acted as stoker, we might still have "to go from London to Edinburgh in a four-horse coach. If "Wheatstone had limited his education to the manipulative "skill of making musical instruments, space would not have "been abridged or time abbreviated by the electric telegraph." The more a man knows, the more valuable does he become to society. The lower a man is placed on that social ladder which is reared against the wall of our Babel-tower of modern civilisation, the more necessary is it for him to receive such instruction as will not only fit him to hold his original position with comfort, but will help him to climb higher and higher, and draw others up after him.

In our contemporary civilisation, science is everywhere triumphant over mere brute force. The neatly-dangerous and prettily-destructive weapons of Snider and Chassepot are more to be feared than all the desperate heroism of Balaklava charges, or the terrible valour of Hougomont and Inkermann. A Krupp gun is a more dangerous adversary than a whole regiment of dragoons. The death-knell of the chivalry of the Second Empire was rung by the clink of hammers in the workshops of Prussia.

The triumph of intelligence over natural advantages has not, however, confined itself to the battle-field. Science has won far more glorious victories—bloodless though they may have been—in the training-schools and manufactories of Europe. The old fallacy of the necessity for employing labour because labourers would die without employment, was blown away in the smoke of the first locomotive.

Handicraftsmen suffer, not because one of their number invents a machine which does the work of fifty of them, but because the fifty are incapable of doing aught but that special handicraft which they have wearily spent their lives in learning, and whose laboriously performed function is at once usurped by the application of simple scientific principles. Technological instruction, properly applied, will familiarise our workmen with these scientific principles, and the artisan who is thrown out of work by the invention of labour-economising machinery will turn his attention, not to the hindering of the application of such invention to his trade, but to the best means of adapting his own trade-knowledge to the new condition of things. Our workmen will jump with the times, not lag behind them; and though it cannot be supposed that Technological instruction will create Stephensons or Brunels, it will enable artisans to comprehend how Stephenson and Brunel achieved their triumphs, and induce them to assist, instead of impeding, the progress of industrial science.

Intelligent labour is supplanting, and must supplant mere brute force of hod-carrying and barrow-wheeling, and that people will in the future be most prosperous who, so far from pampering the native indolence of its manual workmen by refusing to employ the inventions of more intelligent artisans, cultivates, by every means in its power, the intellect of its operatives, and raises its own average of intelligence to the level of that of competing nations. To do this with rapidity and completeness is the end of Technology, such is the object of the Parliamentary grant, and such the aim of the Committee who have issued this book. Under the superintendence of this Committee a Technological Museum, with laboratories and lecture rooms, has been established in

Melbourne, and at their suggestion the lectures which these notes precede have been delivered to the Victorian artisan.

In conclusion let me urge the consideration of one fact. "Raw material" is not so valuable in these days as is the capacity to use it, and our native-born artisans may hold fast the cheering reflection, that the most prosperous countries are *not* those which possess abundance of natural products, human labour, and local advantages, but those which own the highest quality of skilled and intelligent workmen, who can best apply the discoveries of science to the utilisation of the bounties of nature.

A few words as to the manner in which the course of lectures now printed were received by the audiences to whom they were originally delivered. The delivery of these lectures may be said to be the first systematic attempt made in this city to impart scientific knowledge to persons who, desirous of bringing such knowledge to bear upon their various occupations, had no opportunities of attending the day classes of professors, or of witnessing those experiments upon which hand-books of chemistry and the arts found the majority of their conclusions. The attempt was considered to be eminently successful, but it is but right to add that, if it was so, its success is in great measure due to the zeal with which the Professors of the University, the Government Botanist, the Government Astronomer, and Mr. Foord, assayer to the Royal Mint, entered into the project and sustained the hands of the Committee.

The lectures delivered by Mr. Foord treated of Chemistry, in its application to agriculture, manufactures, and the daily necessities of life. This series was the first of such a character delivered in Melbourne, and was received most favourably by the public; indeed, artisans upon whose particular trade the lectures touched, made repeated in-

quiries as to the chance of their republication in a collected form. Professor Wilson's lecture, as an exposition of a branch of science equally necessary to the artisan and mechanic, was received with eager attention by an audience chiefly composed of working men. It has been to the Committee a matter of regret that they are enabled to publish but scanty notes of a lecture so interesting and well-attended as that of Professor Halford. The very meagre *resumê* which is given at page 15, has been taken from the reports printed by the daily journals. It was a marked illustration of the genuine feeling of the public, that persons would attend night after night and systematically takes notes of the lecturer as he proceeded. A further indication of the sympathies of the public was the *method* in which they chose to attend. There is no more difficult task, as may be seen by a glance at the recorded experience of other institutions, than to regulate the mode of admission to lectures of this nature. The plan adopted by the Committee was to give free tickets to any one wishing to attend, if application was made to the secretary the day before the lecture. Persons not provided with such tickets paid sixpence at the door, and season tickets could be purchased for five shillings. Notwithstanding the issue of free tickets, however, a large number of people preferred to pay, and in no case was the liberality of the Committee abused by the disorderly presence of any person seeking mere amusement. The Lecture-hall can hold an audience of about 250, and 2090 persons attended during the course, of whom 695 paid at the door, and 40 purchased season tickets. Compared with the attendance at similar lectures delivered in connection with the Science and Art Department in London, Edinburgh, and Dublin, these numbers may be considered high.

Lectures of a like character will be continued this year, and the course will embrace Chemistry, Geology, Mineralogy, Phytology, and Applied Mechanics. The Committee hope that by the liberality of Parliament, and the assistance of those interested in Technology, that which has so favourably begun will continue, and that the industrial classes will be able to enjoy the benefits of Technological instruction—essential to the interests of a manufacturing and producing country—and whose manifold advantages, and broad method and meaning, I have feebly endeavoured to set forth in the foregoing brief sentences.

MARCUS CLARKE,
Secretary to the Trustees.

ERRATA.

Page 34, line 14, *for* or *read* in.

„ 37, „ 22, *for* reading *read* readily.

„ 37, last line but 3, *for* course *read* courses.

„ 39, line 2, *for* commission *read* committee.

OPENING

OF THE

INDUSTRIAL AND TECHNOLOGICAL MUSEUM.

INAUGURAL LECTURE,

DELIVERED BY FREDERICK M'COY
(Professor of Natural History in the University of Melbourne, Director of the National Museum, and one of the Technological Commissioners),

ON THE METHODS OF DIFFUSING

TECHNOLOGICAL KNOWLEDGE,

ON 8th SEPTEMBER, 1870.

THE inaugural lecture of the Industrial and Technological Museum was delivered on Sept. 8th, 1870, by Professor M'Coy. The subject chosen was "The Methods of diffusing technological knowledge." The lecture-theatre of the institution was well filled, the audience being, for the greater part, of the kind most likely to benefit by the course of lectures to be given.

His Honour Sir Redmond Barry, in introducing the lecturer to the audience, explained that the lectures to be delivered were intended to be of an instructive character, each one leading on to explain what the next would in its sequence develope. It was not only intended to have the lectures printed and circulated—a syllabus of each lecture would, he hoped, be published before its delivery, so that hearers might come properly prepared in mind for the subject to be treated on. The lectures would be specially addressed to practical working men. There were many men prominent in their particular callings who had avowed to him a strong desire to improve themselves in their daily occupations, and those

men were cordially invited to attend these lectures. It was intended in sober earnestness to instruct those who were willing to learn the great truths of nature, and especially those intimately related to the occupations which daily engaged them in this busy sphere of life.

Professor M'Coy said—We have met here this evening to open the Technological Museum, and I have been requested to give the public a short sketch of the nature of the present movement in favour of the diffusion of technological knowledge amongst the persons, whether capitalists or workmen, interested in the highest development of such industrial pursuits as can be most beneficially carried on in this country.

It is obvious to all of us that there are workmen of great excellence in most branches of industry in the colony; but their number is out of all proportion small compared with the amount of work of the best kind which has to be done. The inferior workmen are, however, often men of high intelligence, and every way fit, in many cases, for a higher position in their callings if they had some means of acquiring the additional technical knowledge which the more skilled workmen have acquired in the Old World, by long, zealous labour under good masters.

At present a worker in any of the lower branches of any trade has no means in this country of obtaining the knowledge necessary for the practice of the higher grades, for which he may have every mental and physical requisite in abundance, as those few who have this additional knowledge, which is additional power, jealously guard it as the source of their own superior remuneration. Even these higher kinds of workers are in almost every instance capable of something in their own line much higher, and for which they have a laudable ambition; but their good intentions, good conduct, and mental and physical powers, are incapable of that reasonable fruition which would benefit themselves and the colony in the higher sphere of usefulness, for want of some necessary technical knowledge which at present is altogether beyond their reach.

Then, again, it is known that there are many industries, either imperfectly established or not tried at all, which are peculiarly suitable for the country, either from the abundance in which the raw material may be found amongst our natural products, or from the disproportionate ratio of the value of the marketable commodity when compared with the cost of bringing it from some other country. These industries can-

not be established or profitably carried out without an abundant capital to pay the workers and maintain an efficient supply of the best machinery and materials. We have no lack of capital, which in former days would have been invested in squatting, but which would now, in many cases, it is known, be invested in those industries most likely to return the greatest profit both to the capitalist and the consumer, if there existed any means of learning at once the very latest improvements in the necessary machinery, the proportions, materials, and mode of erecting all necessary appliances, and precise details of the nature and quantities of the substances to be used in the various stages of the manufacture; so that instead of appearing a mere blind venture, the undertaking would present itself to the man of business as one all the parts of which were known with certainty, and were open to such investigation as prudent men should be able to make before entering upon such an investment.

To supply these wants is the task set before the Technological Commission, and which the trustees of this institution are now preparing, in conjunction with the Commissioners, to accomplish; and I will give you some idea of what has been done, and what is in progress, and some of the intentions yet to be put in practice.

One of the most striking lessons taught by Prince Albert's First Great Exhibition of 1851 was that although the manufacturers and workmen of England produced results, in almost every branch of industry, which for excellence of material, soundness of workmanship, strength, and durability, exceeded in value those of other countries, yet they were so devoid of taste in colour, the beauty of form, and the propriety of ornament, that, as a matter of fact, the inferior but more elegant productions of the Continental workers suited the market so much better for very many products, that the necessity became evident of publicly educating the weavers, the furniture-makers, and the house-decorators, as well as all those engaged in the manufacture of papier mache, glass, porcelain, ornamental metal work and jewellery, in the general principles of taste, as deduced from the study of the finest works for form and colour to be studied from all ages and all countries. And a great movement, which has since regenerated the manufactures of England, was made, at the national cost, to establish numerous schools of design and art in all the manufacturing localities, in which skilful masters should teach the young work-people the elements of drawing, free-hand, from the round,

from natural objects, and from the very finest examples of human excellence in form from the antique of Greece and Rome, and in colour and composition of ornamental designs for flat surfaces, chiefly from Eastern sources.

The Technological Commissioners here have followed this example, and having in one of their earliest reports to the Governor pointed out the great preliminary importance of diffusing a knowledge of the different kinds of drawing amongst the members of the different trades, they determined to invite representatives of each of the chief trade societies to which the matter had an important relation, to consult with them as to the best means of carrying out the project with the least cost, by making use of the existing machinery of the different trade societies, with their local halls or meeting rooms. It was explained to the carpenters, joiners, blacksmiths, and engineers, that it was desired to establish classes for teaching mechanical drawing and the use of instruments designed for the accurate laying down on paper the precise details of construction of any building, machine, or smaller mechanical work, for which it would be necessary to prepare accurate technical working drawings before the patterns for metal castings, or the shaping of the other materials could with propriety be undertaken. To the house-decorators, carvers, and ornamental workers of other trades, it was explained that it was intended to assist night classes in the various localities, in which competent masters would give instructions in free-hand drawing of all the different kinds likely to be useful to each, by improving the hand, the eye, the judgment, and the taste of the workman, so as to increase his own prosperity, and at the same time increase the beauty, elegance, and value of all the works of our adopted country —which I hope to see second to none in these respects. The views of the Commissioners were taken up with extraordinary enthusiasm by the organisations of the different trades, the house-decorators, with their secretary, Mr. Roberts, leading the way in the immediate establishment of Trades Art Schools of this kind in many places in the city and suburbs, in conjunction with the Technological Commissioners, through whom the aid given from the public purse is distributed in the form of a small payment for the teachers (on the plan of that given by the English Department of Science and Art), and desks, models, and patterns, of which latter the best examples made use of by the corresponding English department, have been ordered in considerable quantities from home, so as to furnish each of these Art Schools with a permanent series of the best models

for study and imitation. The small cost to the State at which this good work has been so far carried on so energetically and successfully, reflects the highest honour on the Victorian tradesmen as a body.

This establishment of numerous elementary Art Schools in connection with the Trades Societies has been, a few months ago, followed by the permanent appointment of two eminent artists to act as public instructors, in this building, of those who desire to cultivate their talent as artists. The first appointment was that of Mr. Von Guerard, who has lately been decorated by the King of Prussia in recognition of the extraordinary merit of some of the least of his productions in the great department of landscape painting which he has exercised to our delight amongst us for so many years, and whose instructions in this branch of oil painting, as well as sketching from nature, cannot fail to exercise a most happy influence on the career of the many young artists of both sexes who have displayed such great natural talent in their unaided labours in copying the best landscapes in our, as yet, infant Fine Arts Gallery, which bids fair to present to our view at no distant time a collection of pictures the possession of which will be an honour to the colony, as well as to Sir Redmond Barry, to whom we owe the beginning of this, as of so many other of the more elegant and enlightened public undertakings which have raised Victoria so much in public estimation. The second appointment was that of Mr. Clarke, who, being an Englishman, has received no cross of honour from a sovereign, but who has been most highly distinguished as an artist during his earlier career in England, being a gold medallist of the Royal Academy, possessing the extremely rare combination of talent and knowledge enabling him to gain the prizes in the most important artistic competitions in England *both* for figure and landscape; and having been for several years at the head of some of the most important public Art Schools of England. His anatomical knowledge, mastery of perspectives, light and shade, composition and colouring, with his kindly, encouraging manner towards his pupils, will, I am sure, render his aid in the department of art over which he presides equally creditable to himself, beneficial to the students, and satisfactory to the Trustees who have appointed him.

In connection with the labours of these two masters, the National Gallery of Pictures both originals of modern artists, and copies from the unapproachable great master-pieces of the

inspired artists of past times; and the collection of sculpture and casts of the more famous statues of antiquity will by the liberality of Parliament be judiciously increased year by year.

It is hoped that hereafter a competent master for mechanical and architectural drawing for the young engineers of the colony may be added, and perhaps provision may be made for practical instruction in modelling, preparatory to sculpture and carving in stone, wood, and metals.

The next suggestion of the Technological Commissioners was that means should be adopted for providing instruction in the public schools, receiving State-aid, in the elements of mathematics, mechanics, and other branches of Natural Philosophy of almost universal use in the various trades, and which must be learned while young to allow time for the man to grapple with the subjects afterwards, as they will, we hope, be treated in the lecture-room of this Technological Museum, in lectures of a more advanced kind on those portions of the subject having a more immediate bearing on the various industrial pursuits.

The next branch of our subject is Chemistry; which, being at the foundation of nearly all industrial arts and manufactures, demands the most serious consideration from those on whom the responsibility has been placed of recommending the expenditure of public funds for the furtherance of technological instruction in those branches most likely to benefit the community at large. Chemistry, I need scarcely tell you, is a very large subject, and in these latter days, when art seems by its excessive lengthening to dwarf the span of our individual lives to a most ridiculous insufficiency, no man can pretend to teach it all in any course of lectures; but the subject, to be really useful, must be broken up into applied portions, specially suited to the particular object in view. Thus, at the University, the general principles of Chemistry are dealt with; at the University Medical School, Medical Chemistry is specially treated of; but if the Technological Institution is to be a success, we must have separate courses of Chemistry—one applied to agriculture, another applied to metallurgy, and others applied to all the principal groups of trades and manufactures in which it plays an important part—as well as a provision for instructing students in the practice of analysis, and carrying out all the details for themselves of the chemical operations involved in their future pursuits. Of this great fundamental subject it gives me most sincere

pleasure to be able to state that provision has been made on this year's estimates for the appointment of a Chemical Superintendent of the proposed Technological Museum, and that the office has been conferred on Mr. Cosmo Newbery, a gentleman well-known for his discoveries in colonial paper-making, and for the numerous analyses he has made for years for the Mining Department. Mr. Newbery was nominated in England, as the most distinguished chemist of the English Government School of Mines, for the office of chemist or analyst to our geological survey, with which he remained connected to the last. He is one of the rising school of American chemists, who, with the utmost skill and careful accuracy of the scientific details of every chemical work they take in hand, have departed from the common practice, and benefited the world so much by specially devoting themselves to the useful applications of the science to the practical purposes of life, rather than consulting their own scientific fame by labouring at more theoretical researches, or rare combinations of no immediate use to mankind. He has, after leaving America, studied with distinction in the Jermyn-street School of Mines and the famous connected College of Chemistry, where Hoffman has so greatly added to the debt the arts owe to chemistry by his discoveries, amongst many others, of so many of the new valuable tar dyes. From my personal knowledge, and from having often discussed his analyses with him, I may confidently say there are none of the younger chemists of the day the results of whose chemical investigations could be received with more complete confidence than his, not only from the skill and exhaustive care with which every substance in a compound is sought for, but for the singular precision of his quantitative determinations. A laboratory is now being fitted up in this building, with the needful appliances, to enable him shortly to undertake the practical tuition of persons desiring to prosecute analytical researches of all kinds; and furnaces will be erected in which the various processes of reducing metallic ores and conducting assays may be carried on for the instruction of mining managers and assayers, and others qualifying themselves for the practice of metallurgy.

As so much of the wealth of this colony is due at present to its gold mines, it has been thought desirable to appoint a special lecturer on mining, as perhaps in no country in the world in which so much capital is embarked in mining is there so much loss from the employment of incompetent mining managers, and from the want of any means for instructing them

in their duties, or the different essential branches of knowledge, in some of which even our best managers are often avowedly deficient. England was one of the last of the mining countries to take the reasonable step of establishing at the public cost a School of Mines, on the general pattern of those long in operation in all continental and American countries having any important mineral natural products. About twenty years ago Sir Henry de la Béche succeeded in obtaining the consent of the English Government to establish the Jermyn-street School of Mines, and as some interest is felt in Victoria as to the courses of instruction necessary to constitute a complete school of mines on the home pattern, I will enumerate those forming the three years' course:—

MATHEMATICS,
SURVEYING,
CHEMISTRY,
NATURAL HISTORY (including PALÆONTOLOGY),
PHYSICS (or NATURAL PHILOSOPHY),
APPLIED MECHANICS,
METALLURGY,
GEOLOGY,
DEMONSTRATIONS IN PALŒONTOLOGY,
MINING, MINERALOGY
MECHANICAL DRAWING.

In addition to those regular courses there are the chemical and the metallurgical laboratories open for the instruction of students. Of these twelve courses ten are already given in our Melbourne University, where for such purposes any single course can be taken by any person, as a non-matriculated student, without any previous examination; so that the two lectureships on mining and on metallurgy are the only ones required as new appointments to complete our provision in Melbourne for the establishment of an efficient School of Mines on the best home pattern. The appointment of Mr. Newbery, to which I referred, provides for the lectures on metallurgy, and in the laboratories at present being fitted up in this building he will conduct the whole of the chemical and metallurgical laboratory practice. Some arrangement may probably be made for using the present lecturing and examining powers of the University in conjunction with the additions, not found there, which have been provided in this institution, so as to combine all the public teaching provisions we have in the colony of the required kinds for the establishment of a

thoroughly efficient School of Mines. The National Museum of Natural History, which requires for its due preservation to be placed in the middle of a large planted park, is now arranged close to the University lecture-rooms, in such a way as to show the bearing of all the branches of Natural Science on each other, and on palæontology, or the study of the extinct forms of animal and vegetable life, found fossil in the different rock formations, which according to modern geologists can only be determined by their means. This connects the living and fossil series with geology and mineralogy; and the application of economic geology to the two useful arts, Mining and Agriculture, has been illustrated by a carefully prepared series of small models of machinery, in view of at some period Schools of Mining and of Agriculture, such as exist in most modern universities, being founded. All this may be made to work harmoniously, without loss or collision, with the new work commenced in this Technological Institution.

I now come to the second appointment which has been made, and which provides for a systematic course of lectures on Mining, and also for a more detailed course on mineralogy than time will allow at the University. These subjects have been confided to Mr. George Ulrich, a gentleman well-known for many years in the colony as one of our most valued scientific observers. On his first arrival I had the pleasure of securing his aid for the Goldfields' Commission; then, having shown his powers, he became one of the most distinguished of the officers of the Victorian Geological Survey, with which he remained to the end. He is, to my knowledge, a most accomplished mineralogist, having, so far as I know, no equal in this branch of the subject in the country, and fully able to impart instruction of the highest kind in this department. But most interest, perhaps, attaches to his qualifications as a lecturer on mining; and here I need only say that he has himself gone through the complete systematic course of instruction in one of the most famous mining schools in Europe, that of the Harz; and there, to my knowledge, his memory is still affectionately cherished by our common friend, Prof. Römer, as one of the most promising students of his time. I may add that I know him not only to be intimately acquainted with every branch of his subject, but to have bestowed so much pains on the preparation of a course of lectures, to extend probably over greater part of a year, as gives assurance that this portion of the plan will be well carried out.

There are few subjects on which more erroneous notions are prevalent here than the nature of the information conveyed in a course of lectures on mining—most people settling the question in their own minds as if it embraced all the courses I have set down as the full *curriculum* of the mining school; but as this is not so, I will illustrate to you the real nature of such a course, as one amongst the others, and really coming properly towards the close of the instruction on the other subjects. A lecturer on mining, in a complete mining school, addresses his audience first by telling them that if they have to commence and conduct some great mining work for some particular ore, they must first make a geological preliminary examination of the adjoining country to see how the rocks lie, and to make sure that they are about to commence their work in really the proper formation; but he would say, "I will not show you how to do this, as you have learnt it in your course of lectures on Geology;" then he would say, "You must note the fossils of each stratum, so as to be sure that you continue in the right one. How to do this," he would say, "you have learnt in your course of demonstrations on Palæontology." You must then find your vein, and make sure that the ore there occurring is really the one you seek; "how to do this you have learnt in your course on Mineralogy." Having satisfied yourself so far, the next step is to make an accurate survey and plan of the ground; "how to do this you have learnt in your course of Surveying." Then would begin his own peculiar part, in which he would draw your attention to all the circumstances which must be taken into consideration before you begin to open the mine, such as the conditions of drainage, the most advantageous mode in each case of getting the material to the surface, &c. And then he would show you how to begin to open the mine; all the blasting and other tools, with their uses and peculiar advantages, would be shown and explained; and then he would show that the works would probably fall in without an elaborate and costly system of supports by wood or masonry; and here you would be gravely reminded of your duties and responsibilities in this part of your work, that you do not waste the money of the proprietors by employing an unnecessarily large quantity of supports, nor endanger the lives of the workmen or the stability of the works, by employing too little; but he would say, "The methods of calculating pressures and strains, and the strength of materials in different methods of construction, have been taught to you in the courses of lectures on Physics and Applied Mechanics." Then he

would instruct you in all the best methods of raising the ore by windlass, horse-whim, or steam-power, and the laying down rails, and the employment of the proper trucks, &c., below. Then you would be told the time had come for furnishing the mine with the proper machinery, and that it is your duty to prepare accurate working drawings from which the carpenters and smiths, and founders, may tender for the constructions, and make them so that when delivered they may be found exactly fit for their work—" How to do this you have been taught in your course on Mechanical Drawing," he would say. Then the pumps must be ordered, such as may exactly do their work—" This you have been instructed in from the lectures on hydraulics, in your course on Physics." The steam-engines have then to be selected, and kept under constant supervision to be certain of their perfect efficiency—" How to do this has been taught in your course on Applied Mechanics." Then he instructs you from himself in the arrangement of the workmen, and the methods of saving their strength by contrivances for carrying them safely up and down the shafts, &c., and the provisions for ventilating, &c., lighting, in ordinary cases, or where safety-lamps have to be used, &c. Then he proceeds to deal with the heaps of ore got to the surface, and instructs you in the methods of classifying, crushing, washing, &c. Then the furnaces for preparing the materials for market, and all the roasting and smelting processes are alluded to as " a branch of the subject fully dealt with by the lecturer on Metallurgy;" and thus, coming to an end of his subject, you find the lecturer on Mining combines into one focus, as it were, for his special industry all the knowledge conveyed by the other teachers of the school, not by repeating what they have said, but by taking for granted all the knowledge to be obtained from them, he gets time to impart his own additional peculiar instruction which crowns the whole, and from the complete mastery which Mr. Ulrich has of his subject, I can congratulate you on having been so fortunate as to secure his aid, and in the old language of his native valley, I wish him " Glück auf."

I have scarcely left myself time to allude to the next great means of conveying technological instruction—namely, the Technological Museum, or Museum of Arts and Industry. As in England the South Kensington Museum was intended to perpetuate, as it were, the educational advantages of the Great Exhibition, so here it has been determined to commence a Museum which, avoiding some of the extravagant faults of

the South Kensington Museum, may be expected to be of great and permanent benefit to the community by exhibiting complete illustrations of all the materials, tools, machinery, and processes of the most improved kind, requisite for carrying out successfully any and all of the manufactures likely to be profitable in the colony. So that if a capitalist desiring to invest money in some manufacture of the details of which he is ignorant, but which he sees to be profitable, were to come here with his foreman, he could see in one compartment everything which he would see in a well-ordered factory of the kind he wished to establish; he would see if all the necessary materials were really to be had in the country, and no mistake would be made by ordering ineffectual machinery; all would be perfectly illustrated, with the latest knowledge kept "up to Saturday night," as the saying is; Mr. Newbery having the superintendence.

It is intended to take one subject up at a time, and devote all available funds to illustrate it thoroughly, and not yield to any temptation to make the Museum a mere disorganised accumulation of unconnected specimens of imperfectly illustrated, and therefore useless, subjects.

The best patterns of every kind of artistic work will be provided from time to time in addition to those already acquired, so as to educate the common eye and taste by the ancient method of providing examples of the highest excellence for the gratuitous inspection of the public. Specimens of the most beautiful porcelain, tiles, carvings in wood, marble, and metal, engraved gems, embroidery, and ornamental metalwork will be selected, with a due regard to economy, as types which local artists must aspire to excel. And then all the more homely industries will have justice done to them in the order of their importance. The manufacture of the parts of sheep and cattle into forms for the market, most profitable to the colony, will receive the earliest attention —including full illustrations of materials and machinery, and proceedings for making leather, glue, candles, soap, woollen cloth, &c. The dyeing, paper-making, manufacture of salt, gunpowder, sulphuric acid, and many other commodities for which we have the raw materials in the colony, or (as in the case of the New Zealand sulphur) near at hand The inferior kinds of glass and pottery have their cost most disproportionately enhanced by the expense of carrying them from England, owing to the great comparative space they occupy, and their liability to breakage; while the materials for producing them

exist in the colony in abundance, and only await some such trustworthy exposition of the methods of manufacture as this museum will display, to give rise to profitable employment to hundreds of workers, and a profitable local employment for capital.

Wine-making and the distillation of various kinds of spirits, such as brandy from the refuse, will be so fully illustrated with the most improved contrivances for producing the best results with certainty, as cannot fail to be of great value to rich and poor, now so extensively interested in vine-growing.

In all these, and many other industries, the materials will always have complete analyses of their constituents displayed beside them, and this will be most carefully carried out in all the agricultural branches, so as to show the exact nature of the relation between the constituents of a plant and the soil in which it grows. All the soils of the colony will be exhibited with their analyses, and the principal kinds of crops will have their constituents set forth, so that a land selector can see before trial what crop is likely to succeed on his land, or if he want some other crop he can see what constituent he must add as an artificial manure to his ground to meet the case. All the more common kinds of manure will be treated in this manner, and the precise use and mode of action of each will be rendered evident, so that the proper kind may be chosen with certainty for the production of any kind of crop, and many of the popular but nearly worthless kinds be avoided.

Thus I every day see the market-gardeners about Brighton spending great sums in carting sea-weed from the beach for manure, while it will be shown here of what sea-weed consists; and it will be seen that eight-tenths of what they cart is only water, and what remains could for far less than the cost of the cartage be obtained from other sources. A collection of common articles of food for man and beast will be similarly illustrated, so that the value of each may be seen at a glance. I will give you an idea of a beginning I made of a series to illustrate a food collection in the same way. A large potato was carefully modelled and the cast kept to resemble the original, which was then analysed, and beside the model was set a large bottle of water weighing nearly as much as the whole potato, a little bottle of charcoal weighing a small proportion, and all the rest of the constituents forming a mere fraction of the whole. The worthless nature of the great bulk of most kinds of food will be strikingly

demonstrated in this way, as well as the real nature of the difference between one kind of food and another. The stock breeder will see from such analyses, and the tables, why one food will promote the growth of fat, while another kind will grow muscle and increase the strength, while yet another will enlarge the bones, as may be required.

I have now briefly and imperfectly fulfilled my task of giving you a sketch of the methods of diffusing technological knowledge in our new home, and in wishing the undertaking success, I will remind you that the liberality of Parliament, which has never been wanting for any good work, was in the first instance secured for this purpose by the exertions of His Honour Judge Bindon, whose efforts are now crowned with success by the opening ceremony of this evening.

NOTES OF A LECTURE

BY

G. B. HALFORD, M.D.

(Professor of Anatomy, Physiology, and Pathology in the University of Melbourne).

ON THE CIRCULATION OF THE BLOOD,

ON 22nd SEPTEMBER, 1870.

THE third of the series of lectures in connection with the Industrial and Technological Museum was delivered on Thursday, September 22, in the lecture room of the institution, by Professor Halford, on "The Circulation of the Blood."

Professor HALFORD said that the Architect of our frames and of the universe had in the construction of the heart proceeded with a great deal of artistic effort to a very complex end. It was the seat of the force or forces regulating the circulation of the blood. The "circulation of the blood" means literally that the blood passes within a circle, for the blood proceeds from the left side of the heart throughout the frame and all its ramifications, and returns again continually to the heart, thus making a complete circuit. When it leaves the heart it is red, or arterial blood; and when it returns it is blue, or venous blood. The reason of the difference in colour is that in coursing through the lungs it is exposed to the action of the air, and is oxygenated pure, while by the time it returns it is deoxygenated, impure, and blue. Each time it returns it is again exposed to the air, and becomes ready for another circuit, so that it returns to the left side of the heart revivified, and is distributed throughout the whole body.

The Professor then proceeded to explain the action of oxygen on the blood, and pointed out that in fish gills supply the place of lungs, while the water, which contains a large quantity of oxygen, supplies the place of the air. He also pointed out the difference between the hearts of reptiles and some of the lower animals and that of man, and illustrated this part of his subject by diagrams. On the circulation of the blood, he proceeded to say, the vitality of the being depends, and hence it had become the most enticing of all subjects to physiologists. Harvey, who wrote in the reign of Charles I., explains most minutely all the movements of the heart, and his work is one

of the finest pieces of writing in use. His knowledge of anatomy and the circulation of the blood in all the animal kingdom must have been very great indeed. As to the force of the circulation, it had been asked how it was known that the pulsation or pumping of the heart was sufficient for the whole body. Looking at a diagram of the heart, it would be seen that the right side is very weak compared to the left, and the orifices are in proportion to the velocity with which the blood is required to flow; and whenever there are obstacles caused by disease, the heart increases in size just in the same manner as a blacksmith's arm is increased in size by activity. In fish, it was urged, the gills would break the force of the flow of the blood, but their hearts are proportionately much more powerful than in mammalia or reptiles.

The principles of capillary force were then explained by some simple experiments, and it was shown that this has no doubt some effect on the force of the blood. The effect of oxygen on the blood was shown by a simple experiment with ozone, guaiacum, and the colouring matter of blood, the principles of which were first discovered by Schomberg, and afterwards, as the Professor said, intelligently worked out by Dr. Day, of Geelong. By this test the oxidation of blood could be easily discovered. At night the heart stores up oxygen for consumption on the following day, and he therefore recommended all who could do so to sleep in well-ventilated places. The beating of the heart is not subject to the will, and is imperceptible when it is in a healthy state. The pulsation commences in the embryo long before there is a muscular formation of the heart, and it is most interesting in the different animals to watch its progress from day to day. Then the diaphragm is continually drawing in air, as the heart goes on, without our knowledge. This pulsation had been a very difficult subject to determine, and it had been discovered that the heart of a reptile pulsates for some time after it has been removed from the body. The circulation of the sap in trees was referred to, and the action of the human heart was then explained minutely by means of diagrams, as well as the different arteries and blood-vessels conveying the blood over the body. Of the power of the heart it had been computed that if employed in lifting alone, it would in one hour lift 19,740 times its own weight. The most perfect engine yet made was one between Vienna and Trieste, capable of lifting 2700 times its own weight; so that the heart is seven and a half times more powerful than the most perfect engine ever made by man. At the conclusion of his lecture the Professor was loudly applauded.

THE CONSERVATION OF ENERGY:

A LECTURE,

DELIVERED BY WILLIAM PARKINSON WILSON, M.A., F.C.P.S.
(Professor of Mathematics in the University of Melbourne),

On 8th OCTOBER, 1870.

If I understand rightly the object of this course of Technological Lectures it is not intended that they should in any way take the place of that mode of practical instruction which may be generally described as apprenticeship to a trade or profession. It must not be supposed that attendance on any number of lectures, no matter how skilfully they may be prepared, how amply they may be illustrated, how carefully they may be listened to, will render unnecessary that training of the hand, the eye, the judgment, which can only be acquired by actually doing as a learner the subordinate parts of that work the higher parts of which will afterwards be the occupation of the skilled workman. But as all the arts of life consist in obtaining natural products, and adapting them for the use of man, the workman who, in addition to the dexterity and knowledge and judgment obtained by ordinary training of the nature of apprenticeship, possesses also a full knowledge of the mode of production of the substances used, of their properties, and of the natural laws which govern the processes employed in their manufacture, will be able not only to perform satisfactorily the routine work of his trade, but will be armed also to encounter unforeseen difficulties, to give the fullest effect to all new discoveries bearing on his occupation, and to remedy defects and introduce improvements into the ordinary processes.

If two workmen have equal manual skill in any occupation, one of them, who in addition has a scientific knowledge of the subject matter of his work, cannot fail in the long run to take the lead of his companion who has none.

And since the application of power in some way or other forms so large a part of all the useful arts, and year by year power derived from inanimate objects and applied by ma-

chinery is more and more substituted for horse-power and manual labour, while the function of the human being becomes more and more to direct and control these inanimate labourers, it seemed to me that an attempt to explain, simply and definitely, and in language as far as possible free from technicalities, that great natural law which governs the production and expenditure of all power would not be unsuitable as one of these introductory lectures. I shall not commence with a statement of this law, because such statement, given without a previous full and careful explanation of the meaning of the words used, would be unintelligible, or at best vague and indefinite; and the explanation of the words employed can best be given by tracing in order the several steps in the building up of the ideas which those words are intended to express.

As a clear and definite understanding of these ideas and words is indispensable to an understanding of the principle, I trust that I shall not be considered as undervaluing your intelligence and knowledge when I occupy some short time over certain elementary matters which I hope and believe are common every-day truths to you. It is only by starting thus from what is well and surely known that we can fix without vagueness the meaning of the terms we use.

I will in the first place invite your attention to what are known as the simple mechanical powers—the lever, the pulley, the screw, and so forth. Any stiff bar of wood, metal, or other material which is moveable about a point that remains fixed for the time is a lever. The crowbar used to move a stone or log, or to prize open a box, is a lever, the fixed point about which it turns being called the fulcrum; the beam of an ordinary pair of scales is a lever; each half of a pair of nutcrackers is a lever; and so forth.

Now most levers have a long arm and a short one, and the usefulness of the lever consists in the fact that a small pressure applied at the end of the long arm produces a large pressure at the end of the short one; and the large pressure so produced is as many times greater than the small pressure which produces it as the long arm is longer than the short one. Thus, for instance, if the short arm is three inches, and the long arm five feet—that is, twenty times as long—a pressure of a hundredweight at the end of the long arm would produce a pressure of a ton at the end of the short one. There are many simple machines which are substantially levers; the windlass, for instance, in which the handle is the long arm, and the axle round which the rope is coiled, or rather the

radius at that point where the rope leaves it, is the short one. In any train of wheelwork we have generally a wheel and a pinion on the same axle, the leaves of the pinion gearing into the teeth of the next wheel of the train; in this case each wheel, with its pinion, is a lever, that radius of the wheel which passes through the particular tooth in action being the long arm, and the leaf of the pinion in gear at the time being the short one.

In all these cases the rule I have referred to is applicable. The power exerted at the end of the short arm is greater than that applied at the end of the long one in exactly the same proportion that the long arm is longer than the short one. By this rule, however complicated the machinery, it is possible, when the sizes of the several parts are known, to calculate the power exerted at one part of the machine in consequence of a known power applied at another part.

There are two points in the application of this rule which it is necessary to bear in mind: first, that all the parts of the machine are supposed to move without friction; this, in fact, can never be the case, and the force arising from the friction is in practice one of the forces that has to be overcome by the power applied. I will dismiss this question of friction for the present, but will return to it by-and-bye, when it will form a most important subject of our consideration.

The second point is, that the pressures, to comply with the rule above stated, must act strictly at right angles to the arm of the lever; that is, the direction of the pressure acting at any point must be truly square to the line which joins that point to the centre of motion. If the pressure acts obliquely to this line part of it is wasted in producing pressure on the axis, and so increasing friction, and that part only which is exactly square to this line is effective in moving the machine. Since, when a lever turns on its fulcrum, or a wheel or crank revolves on its axis, every point in it describes a circle, or a portion of one, round the centre of motion, and since every part of this circle is strictly at right angles to the radius at that point, we may state the rule for the efficiency of a force in other words by saying that a force is *wholly* efficient only when it acts exactly in that direction in which the point where it acts begins to move, or in exactly the opposite direction.

It would seem to follow from this principle of the lever that by a suitable combination a pressure of any magnitude whatever may be produced by the application of a moderate force, and it was this which led Archimedes to exclaim boast-

fully, when he first realised it, "Give me somewhere to stand upon, and I will lift the whole world." But—and upon that *but* the whole subject of my lecture turns—when any combination of this sort is put in motion, as it must be if it is used to do work, the distance through which the point where the less force acts moves in the direction of that force, exceeds the corresponding distance for the greater force in exactly the same proportion as the greater force exceeds the less.

In the first example, for instance, where a pressure of one hundredweight produced a pressure of a ton, the point where the hundredweight acts would have to move through twenty inches to produce a motion of one inch in the ton. And this is true in any machine whatever, however complicated, whatever combination of wheels and levers, screws and pulleys, may enter into it; always, of course, leaving out of account the loss due to friction. This must have forced itself on the attention of any one who has watched a couple of men raising some huge stone, or some large mass of iron, by means of a crane. The men exert their pressure on the handle of the winch, and as they turn it round and round many times, the weight raised travels upwards so slowly that its motion is only noticed when carefully watched. The whole distance through which the handle travels bears the same proportion to the height through which the weight is raised, as the weight itself does to the pressure exerted by the men's hands. I will not occupy your time by multiplying examples, but I must ask your attention to another way of expressing this result; the change is merely an arithmetical one, but the altered form of expression marks an era in the history of the subject. If you express the power applied at one end of the machine and the power exerted at the other end in terms of the same unit, say in pounds; and likewise express the distances through which the points where these forces act move respectively in feet; then four numbers will be obtained: a number of pounds and a number of feet for one end of the machine, and also a number of pounds and a number of feet for the other. If the first two numbers be multiplied together, the result will be the same as when the second two are multiplied. Thus, if a pressure of 50 lb. be used to raise a weight of 1000 lb. ten feet, we know from our former rule that it must act through a distance greater than ten feet in the same proportion that 1000 lb. is greater than 50 lb., *i.e.*, through 200 feet; and we see also, in accordance with the second statement, that 50 multiplied by 200 gives the same product as 1000 multiplied by 10.

We see, then, that though machinery will enable us to modify to any extent we require the amount of pressure we exert, this particular product I have referred to, viz., the number of pounds in the pressure multiplied by the number of feet through which it is exerted, can not be altered (except so far as it is apparently lost by friction). To this product the name "work" is especially assigned; and throughout the remainder of this lecture, when I make use of the word "work" I shall use it in this technical sense, and in no other. The idea implies a force exerted through a distance, and when the force is expressed in pounds and the distance in feet, then the work is expressed in foot-pounds. Thus, if we speak of 1000 foot-pounds of work, it may mean one pound raised 1000 feet, or 1000 lbs. raised one foot, or 100 lbs. raised ten feet, or any other pair of numbers whose product is 1000. All these different forms which 1000 foot-pounds of work can take can be converted into one another by machinery. This idea of work, as expressed in foot-pounds, is so important that I will give one more illustration of it.

Suppose that a clock is required to strike hours on a large bell; it is found that to bring out the full tone of the bell a hammer weighing 40 pounds is necessary, and that it must fall nine inches at each stroke; it must, of course, be raised nine inches for each stroke, and to raise a weight of 40 pounds nine inches requires 30 foot-pounds of work. The hammer must be raised 156 times in each 24 hours, thus requiring 156 times 30 foot-pounds of work, *i.e.*, 4680 foot-pounds. If there is only a fall of 20 feet for the weight, then a weight of 234 lbs. is required for the actual work done, in addition to whatever else may be found necessary to overcome the friction of the machinery.

But work may be employed for other purposes than to overcome a resistance. When a weight is raised to any height it can in descending do a certain number of foot-pounds of work; as, for instance, the clock-weight in the last example. If such a weight is detached from the machinery and falls freely, as it approaches the ground it is deprived of that power which it possessed in virtue of its elevation. Let us consider its state the instant before it touches the ground. It is moving with a velocity strictly dependent on the height from which it has fallen, and the mass so moving possesses in virtue of that velocity a power of doing work precisely equivalent to the work expended in producing it.

It is important to consider the exact numerical relation

between the velocity and the work so expended, and to fix the ideas, let us call the velocity of a body which moves uniformly at the rate of a foot a second, 1; then if a body moves at the rate of 8 feet a second, its velocity will be 8, and so on. Now if a body falls from rest through one foot it will acquire at the end of its fall a velocity of 8 feet a second, *i.e.*, a velocity which we call 8. So that when a weight of one pound falls one foot, the expenditure of one foot-pound of work produces a velocity 8 in a mass of one pound.

But if this pound weight goes on falling through a second foot its velocity will not be doubled; it will, in fact, require a fall of 4 feet to produce a velocity 16; and in like manner it will require a fall of 9 feet to produce a velocity 24, and a fall of 16 feet to produce a velocity 32; so that a mass of one pound moving with the several velocities 8, 16, 24, 32, corresponds to the expenditure of 1, 4, 9, and 16 foot-pounds of work respectively. The velocities it will be seen are proportional to the numbers 1, 2, 3, 4; the work expended, to the numbers 1, 4, 9, 16.

This is expressed in mathematical language by saying that the work expended in producing any velocity is proportional to the square of the velocity, and we obtain this practical rule: multiply the weight in pounds by the velocity in feet per second twice over, and then divide the product by 64*—the result will be the number of foot-pounds of work required to produce this velocity.

Hence, then, a mass of matter in motion is a form in which the power of doing work may be stored up just as it may in a weight raised to a height, and the amounts of work so stored up in each form are connected together by the definite numerical relation embodied in the rule just stated. Now it is this power of doing work to which we give the name "energy," and the two forms in which we have seen that it may exist, and which are convertible into one another, have been well termed energy due to motion, and energy due to position. The more usual terms are, for the former "kinetic energy," and for the latter "potential energy." When, then, we speak of kinetic energy, we mean energy stored up in a body in motion, as in the fly-wheel of an engine; and by potential energy we mean energy stored up in some body in virtue of its position, as

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* More accurately 64·3 in this latitude. The formula is

$$Wh = \frac{Wv^2}{2g} = \frac{Mv^2}{2}$$

in a clock-weight when wound up, or a head of water in a reservoir.

When a body is projected upwards with any velocity, it possesses in virtue of that velocity a definite amount of kinetic energy; as it rises, the velocity and consequently also the kinetic energy decreases, but this decrease of velocity corresponds to a greater height attained by the body, and consequently to an increase of potential energy. If the energy due to velocity and the energy due to position be added together, the sum of the two will be unaltered during the whole motion of the body.

So long as the body does not receive an accession of energy from some source external to itself, or part with it to some body external to itself, the total amount of energy existing in it will remain the same; its distribution between kinetic energy and potential energy may vary to any extent, but the energy itself is as indestructible as matter.

The production of kinetic energy by a moderate pressure exerted through a considerable distance, and the subsequent employment of that energy to do work requiring the exercise of a very great pressure through a small distance, is of constant occurrence. When a nail is driven by a hammer, the pressure of the hand, exerted during the whole fall of the hammer, produces an amount of kinetic energy in the hammer, which on its striking the nail is converted into an equivalent amount of work, represented by the great pressure required to drive the nail exerted through the very small distance which the nail is driven.

Though in this case the work done which corresponds to the kinetic energy of the hammer is easily perceived, it is by no means so easy to perceive in what form that energy continues to exist. It is quite certain that the nail so driven possesses no power of doing work, in the sense in which we have used the term.

It is necessary to consider, therefore, whether or not there is some other form in which energy may exist.

Suppose a ball of lead, weighing one pound, placed at rest so that it is quite free to move, to be struck by another similar ball moving at the rate of sixteen feet per second. Since lead is almost devoid of elasticity, the two balls after the collision will move on together with half the speed, *i.e.*, at the rate of eight feet per second.

Calculate now the amount of energy immediately before and immediately after the collision. At first there was 1 lb.,

moving with a velocity 16. This we have seen is equivalent to four foot-pounds of work. Afterwards there will be 2 lbs. moving with a velocity 8; this, according to our rule, is equivalent to only two foot-pounds of work.

The kinetic energy of the system consisting of the two balls is thus at the instant of collision apparently reduced to one-half its previous amount; but no conversion into potential energy has taken place in that instant: the energy of visible motion which has disappeared must therefore have taken some other form.

Now if the temperatures of the two balls were observed with sufficient minuteness before and after collision, a slight increase of temperature would be found to have taken place. That energy of visible motion which has disappeared has taken the form of an increased temperature of the lead.

The preceding is only an imaginary case; the increase of temperature would be so small that our most delicate instruments would fail to measure it; but if the amount of energy so converted is sufficiently increased, the results are very noteworthy. When a bullet from a rifle strikes a target, the kinetic energy so converted produces heat sufficient to partially melt the bullet; by hammering a piece of metal it may readily be made too hot to touch, and a skilful hammerman will even make a piece of iron red hot. An elevation of temperature is therefore a form in which energy may appear. Whether it belongs to either of the two forms previously mentioned, or is a third distinct form, will be considered presently.

We will first, however, go back to that loss of work which takes place in every machine in consequence of the friction of its parts, to which such frequent reference has already been made. It is well known that friction is always accompanied by the production of heat. Savages light their fires by the friction of two pieces of wood; carriages are set on fire by the friction of their axles; the heat produced by the friction of the grindstone against steel raises to incandescence the particles of steel rubbed off. But notwithstanding this general knowledge of the invariable production of heat and loss of work by friction, it is only in comparatively recent times that the connection of the two has been suspected and established. The difference between the work expended on a machine and the work done by it was supposed to be actually lost, and the heat produced by friction was considered a merely accidental accompaniment.

It was not till the latter end of the last century that mechanical work seems to have been distinctly recognised as the source of the heat so produced.

In 1798, Count Rumford, whilst watching the boring of cannon in the arsenal at Munich, was struck by the great quantity of the heat developed in the process, and the insufficiency of the theories previously put forward to account for it. He was led to make experiments on the subject, and succeeded in boiling two gallons and a-half of water by the heat produced by friction. His experiments do not seem to have been followed up, and though much was written on the subject, it was reserved for Mr. Joule, of Manchester, by experiments conducted within the last thirty years, to prove that whenever mechanical work was used up in overcoming friction, whether of solids or fluids, whenever, in fact, it disappeared as visible work, an equivalent amount of heat was produced, that is, an amount of heat bearing a definite numerical relation to the work so lost. But he did more than this; he showed that in every case admitting of accurate observation where mechanical work was done by the application of heat an equivalent amount of heat disappeared in the process. This statement will require further explanation to make it clearly intelligible. And first let me render definite the expression, a quantity of heat.

I will take for granted that every one is familiar with the meaning of the word temperature, as expressed in degrees of the thermometer in common use; that the temperature of freezing water is 32°, and of boiling water is 212°; that a temperature of 50° would correspond to a cold day, and of 100° to a very hot one. Now these temperatures, or differences of temperature, are not quantities of heat, though they are intimately connected with them.

If a vessel of water is placed over the flame of a gas-burner the temperature of the water will rise, the heat of the flame being conveyed to the water and producing the rise of temperature. If the quantity of water is larger the temperature will increase more slowly, and a longer time will be required to produce the same rise; that is, a larger quantity of heat must be conveyed to the water. Hence, a quantity of heat may be considered as definitely described when we have stated the increase of temperature it will produce in a given quantity of water. If we take as our standard of reference or unit the quantity of heat which will raise the temperature of one pound of water one degree, then quantities of heat can be ex-

pressed in terms of this unit just as quantities of work can be expressed in foot-pounds. Now Joule ascertained as the result of a great multitude of experiments, that one unit of heat is equivalent to 772 foot-pounds of work.

That is, first—when mechanical work is applied so as to produce an increase of temperature, and *no other result*, for every 772 foot-pounds of work so applied heat is produced sufficient to raise the temperature of one pound of water one degree; and second—whenever heat is made use of as a means of obtaining mechanical work, for every 772 foot-pounds of work produced one unit of heat disappears as heat in the process.

This latter point, though now most thoroughly established, is directly at variance with the views formerly held on the subject.

The old idea was, that when heat was used to produce work, as in the case of the steam-engine, the heat simply passed from a body of a higher temperature to a body of a lower—from the boiler to the condenser—just as when water is used to do work it passes from a higher level to a lower. But though in one respect the analogy holds, in another it fails altogether. To obtain work from heat it is necessary that it should pass from a body of higher temperature to one of lower; but here the analogy ends. When water is used to do work as much water issues from the mill at the lower level as enters it at the higher; the water itself is not used up in the process. But in the case of the steam-engine, the heat passing into the condenser is less than that leaving the boiler by an amount corresponding exactly to the work done, one unit of heat for every 772 foot-pounds of work; and that, too, altogether irrespective of any that may be wasted in making the engine-room hot. In dealing with these relations between heat and work it is necessary to examine carefully whether any result is produced other than an increase of temperature, and also the very different changes of temperature that the same quantity of heat will produce in different substances.

The quantity of heat that would raise the temperature of a pound of water one degree, would raise the temperature of a pound of iron nine degrees, and of a pound of lead thirty-two degrees. And again, the heat requisite to convert into steam a pound of water already at the boiling point, *i.e.*, to change a pound of water from the liquid to the gaseous state without effecting any change in the temperature as shown by a thermometer, would raise the temperature of 966 lbs. of water one degree, *i.e.*, 966 units of heat are used up, disappear as heat,

in changing a pound of water from the liquid to the gaseous state. This is the quantity when the change takes place at the temperature of boiling. When the change takes place at lower temperatures, as when water evaporates without boiling, the quantity of heat which disappears is still greater.

But this heat, though latent, is not lost. Like other forms of energy it is indestructible, and may be recovered in the form of sensible heat. If a pound of steam be passed through ten pounds of water, it will raise the temperature of it more than 96 degrees.

We may now take up the inquiry whether heat is an entirely new form of energy, or belongs to one of the two kinds already discussed. According to the best conclusions at which scientific men have been able to arrive, it is strictly a form of kinetic energy, *i.e.*, energy stored up in the motion of matter—but with this difference, that in the cases hitherto considered the mass has been in motion as a whole, while in the case of heat the ultimate particles of the body are moving relatively to one another. It may seem difficult to believe that a piece of solid, inert-looking matter consists of particles in a state of rapid motion relatively to one another; but there are many properties of matter, which it is far beyond the scope of this lecture to discuss, which lead almost inevitably to that conclusion; a rise of temperature according to this view is simply an increase in the velocity of that relative motion. That increase may become so great as to alter entirely the stability of those motions, and the body may in consequence change its state, may pass from a solid into a liquid, or from a liquid into a gas. Regarded in this light, it is easy to conceive the blows of a hammer producing an increase in this vibratory motion, *i.e.*, producing an increase of temperature.

These two kinds of motion, the motion of the body as a whole, and the relative motion of the parts, may perhaps be made clearer by a figure.

The one may be likened to the steady onward-march of a body of soldiers in close column, all preserving the same relative positions; the other to the occupants of a ball-room when engaged in some furious whirling dance. The rapidity of motion, the actual amount of kinetic energy, in this latter case may be far greater than in the former; yet still, considered as a whole, the body of dancers does not change its position—it remains in the same room.

The correctness of this conception of the nature of heat is confirmed by what we know of the manner in which it is

transmitted from one body to a distant one. The phenomena of light prove to us that all space, at least as far as the most distant visible star, is filled with an elastic matter of extreme tenuity, by means of which the vibrations of luminous bodies are transmitted in all directions in what are called waves, just as the vibrations of a bell are transmitted in all directions by the air. The existence of this matter has long passed beyond the stage of hypothesis. The rate of propagation of the vibrations has been measured, and the number in one second corresponding to light of any particular colour has been calculated. Now the various phenomena of light have been found to be so completely identical with those of radiant heat, in all cases in which it is possible to bring them to the test of experiment, as to leave no room whatever for doubt as to the complete identity of light and heat. The vibrations thus transmitted differ in intensity just as one sound is louder than another. They differ in rapidity, *i.e.*, in the number of vibrations in one second, just as musical notes differ in pitch; and just as with vibrations of the air there is a limited range outside which the vibrations are too slow or too quick to produce in our ears the sensation of sound—a range, too, which differs slightly in different individuals—so, also, there is a range much more limited, and also differing with different individuals, outside which the vibrations of the ether are too slow or too quick to produce in our eyes the sensation of light. Yet the existence of these vibrations, and the fact that they follow in all points the same laws as those that are visible, is absolutely certain. The chemical action which constitutes the basis of photography is produced mainly by vibrations which are too rapid to affect the retina as light; while, on the other hand, those vibrations which are too slow to be visible are found to exercise the most potent influence on our thermometric apparatus. And just as the vibrations of the air, originating at some musical instrument, meeting with some glass or string which can vibrate in unison with them will repeat on it their tiny strokes till it becomes itself sonorous, so the vibrations of the ether, originating in the motion of some hot body, are propagated through space till they meet with and set in motion the particles of some other body, thus communicating to it that particular form of energy which is manifested to us in an elevation of temperature.

So far, then, all energy exists for us under one of two forms; potential energy, *i.e.*, energy due to position, and kinetic energy, *i.e.*, energy due to motion: and this latter may be sub-

divided into the energy of visible motion, and the energy of molecular motion; and we have seen that energy in one form may be changed into another form, or may be communicated from one body to another, but that in all these changes and interchanges the aggregate quantity of energy remains unaltered. Since, then, all these considerations lead to the inference that no act of ours can create or destroy energy, it becomes necessary to inquire in what form the energy which when fuel is burned becomes manifest as heat existed before the combustion.

All combustion consists in chemical combination, and all ordinary combustion consists in the combination of the substance burned with oxygen. The heat produced by combustion is therefore the heat of chemical combination. But what is chemical combination? The atoms of bodies which have an affinity for one another, but which exist apart from one another, then rush together, and form compound atoms, or molecules. When carbon is burned, the atoms of carbon and oxygen rush together and form by their junction the molecules of carbonic acid. Let us examine this a little more in detail, and confine our attention to one atom of carbon and the two atoms of oxygen which combine with it. The affinity existing between these is a force impelling the one to the other, just as the weight of a stone is a force impelling it to fall to the ground when dropped from the hand; and just as, in this latter case, the potential energy which existed in the position of the stone apart from the earth and its capability of falling to it was converted by that fall into the kinetic energy of visible motion; so, in the case of the atoms of carbon and oxygen, a potential energy exists in their separation from one another which when they rush together to form a molecule of carbonic acid is converted into the kinetic energy of molecular motion.

The potential energy of one pound of carbon, existing in virtue of its separation from oxygen and power of combining with it, is equivalent to more than eleven million foot-pounds of work.

The combustion in oxygen of one-pound of carbon would produce 14,500 units of heat—*i.e.*, would raise the temperature of 14,500 lbs. of water one degree; or would raise 100 lbs. of water from 67° to the boiling point. Each of these 14,500 units of heat would be equivalent to 772 foot-pounds of work; thus giving, as already stated, more than eleven million foot-pounds.

In like manner, one pound of hydrogen produces by its combination with oxygen heat equivalent to more than 47,000,000 foot-pounds of work.

It must not, however, be imagined that any machines of ours will ever enable us to obtain this amount of energy from the fuel in the shape of useful work. The conversion of heat into mechanical work can only take place through the intervention of some engine in which the heat passes from a body of a higher temperature to one of a lower. A portion only of the heat which leaves the body of higher temperature can be converted into work; some must pass out as heat to the body of lower temperature. No construction of engine is even theoretically possible in which the whole amount of heat should be so converted.

A perfect steam-engine, working with a difference of pressure of four atmospheres between the boiler and the condenser, would convert into work only one-quarter of the heat which left the boiler; thé remaining three-quarters would pass out into the condenser as heat.

The best Cornish pumping-engines do not convert into useful work more than one-tenth of the energy contained in the fuel.

When chemical combination is used in a galvanic battery to produce a current of electricity, the passage of the current through the successive portions of the circuit produces heat, depending on the intensity of the current and the resistance offered by the circuit. If the production of the current is not accompanied by the performance of any external work, the amount of heat so produced throughout the whole circuit is precisely the same as would result from the same chemical combination if no battery were employed; the difference is that the heat is developed in a different place. The heat may be produced mainly at a point far distant from that where the combustion takes place. Electricity in motion, therefore, may be regarded as a means of conveying the energy of chemical combination.

When a battery is employed to do external work, as for instance to decompose water, the heat developed in the circuit will be less than that due to the combustion in the battery; but if the gases into which the water is separated are allowed again to combine, the heat produced by that combination will exactly supply the deficiency.

When the point of junction of two different metals forming part of a circuit is heated, an electric current is caused in the

circuit, and by means of this current the heat so applied is carried away, and reappears as heat in other portions of the circuit.

It would occupy time extending far beyond what is available for a lecture if I were to attempt even to enumerate the various modes in which the character and distribution of energy may be changed; but all are subject to this law—that no energy is ever created or destroyed by any such process.

There is, however, one other case of too great importance to be passed by without notice, viz., when the chemical combination out of which energy is developed takes place in the digestion and assimilation of food by an animal. Accurate experimental determinations of the exact relation between the food consumed by an animal and the work that it can perform are attended with peculiar difficulties. When an animal, be it man or horse, is in good condition, there is stored up in it a quantity of energy available for the performance of a large amount of work. There can be no doubt that all work done by such an animal is accompanied by the abstraction of a corresponding amount of energy from this stock. Every time that the muscles are contracted to exert force, a portion of nerve matter is reduced to a lower chemical state, and if the process is repeated sufficiently often the stock becomes exhausted, and the animal can do no more work till a fresh supply has been stored up. But we know also that the waste goes on even when no external work is done; a man, however idle, cannot continue to live without food; and it is this waste in keeping up the machine, together with the variations in amount of the large stock of energy stored up in a healthy body, of both of which we can take no exact numerical account, which prevent us from arriving at any precise estimate of the efficiency of an animal, when considered simply as a machine for producing work from food. There is, however, reason to believe that the efficiency of animal power is certainly not less than that of the best engines.

We have seen, then, that energy may exist in four forms; the kinetic energy of visible motion, as in a flywheel when in rotation; the kinetic energy of molecular motion, as heat; the potential energy of visible position, as when water is stored in a reservoir at an elevation; and the potential energy of chemical separation, as in fuel.

All these forms of energy are mutually convertible, but the aggregate amount in the universe cannot be increased or diminished without an act of creation. But though the aggregate

amount remains unaltered, it is not in its different modes of distribution equally available for doing useful work.

I have pointed out that in order to convert heat into any other form of energy it must pass from a body of higher to one of lower temperature, and that the conversion of a portion only of the heat is effected. The remainder is present as heat in the body of lower temperature. All the heat that exists in bodies of the lowest temperature at which we can work with them is therefore not available, and all the heat that so passes to the lower temperature is lost, so far as conversion into any other form of energy is concerned. But we have seen, also, that hot bodies radiate heat to other distant bodies, and so part with that high temperature which renders them capable of doing work. There is thus a tendency in the nature of heat to distribute itself uniformly over all matter, and so to destroy those differences of temperature on which its efficiency as a working agent depends. The conversion of chemical separation into work is necessarily accompanied by the production of heat, whether the combination takes place by burning it as fuel, or in a battery, or in the stomach of an animal. All machines, however well-made, are subject to friction; many also to percussion; and both friction and percussion mean the conversion into heat of some other form of energy. If, then, we confine our consideration for a moment to this world of ours, we see that every process carried on upon it is attended more or less with the conversion of some other form of energy into heat, the uniform distribution of that heat over the earth, and the dissipation of it by radiation into space. It becomes, therefore, important to consider what stores of energy are available for us in the earth itself, or obtainable from external sources. I shall not attempt anything at all approaching to a complete enumeration; but shall only briefly refer to the most important.

First of all are our supplies of food and fuel; and these are for the most part vegetable in their origin.

Our food, and the food of all other animals, is either vegetable, or it is the flesh of animals whose food is vegetable. We thus come to the vegetable kingdom as the source of our supply of food.

Again, fuel is for the most part of vegetable origin; either the timber of modern forests, or the timber of pre-historic forests, now converted into coal, or the fat of animals which is ultimately traceable to a vegetable origin.

Hence, then, we must consider that vegetation is one great

agent in effecting that chemical separation the breaking down of which gives us a supply of energy in the form of heat or muscular force.

Whence, then, does the vegetable germ obtain this supply of energy, which it thus stores up in a potential form for our use? The principal constituents of all vegetable matter, which render it of use as fuel, are carbon and hydrogen; and of these, carbon is derived mainly from the decomposition of the carbonic acid of the air and the assimilation of its carbon. And just as heat is produced by the combination of the carbon and oxygen, so energy, in some shape, must be obtained from without to effect the decomposition. It is the action of the sun's rays on the plant which effects the decomposition. The undulating motion of the ether, which carries to us our share of those vibrations which constitute the heat of the sun, and which, communicating itself to inorganic matter, as metal or stone, produces in it merely an elevation of temperature—this same motion, acting upon the organs of plants as instruments, effects the separation of the carbon and oxygen, and is so stored up in a potential form. The vegetable cell is thus able so to modify the energy conveyed to it by radiation from the sun as to perform gradually at ordinary temperatures what the most powerful agencies of heat and electricity cannot do in the laboratory, viz.:—to decompose carbonic acid, setting free its oxygen. How the plants accomplish this change is one of those mysteries of organic life which human science has not yet fathomed. The fact of the conversion into some other form of energy of what without vegetation would manifest itself as heat is obvious to the most superficial observer. Compare the condition of a tract of barren sand or rock exposed to the rays of the sun with the condition of an adjoining tract covered with luxuriant vegetation. The one will be hot and scorching, the other comparatively cool; and yet both are receiving the same amount of heat from the sun, while the barren land being hotter is losing more by radiation. The heat which falls on the land covered with vegetation is not available to raise its temperature as high as that of the barren land, being converted by that vegetation into the potential energy of chemical separation. Thus, when we use coal to drive our engines, we are using that kinetic energy of solar radiation which was stored up in the primeval forests ages before man was an inhabitant of this earth.

Water power and wind power are also two sources of

energy available for our use; and these, like food and fuel, are traceable to the action of solar radiation. The heat of the sun, acting on the surface of the sea and the moist parts of the earth, causes the formation of vapour. The great amount of energy which is required for effecting the change from the liquid to the gaseous form is thus derived from the sun. The water so converted into vapour rises and forms clouds, and falls again as rain, and thus forms the source of brooks and rivers which serve to fill reservoirs—thus forming a store of potential energy—and whose currents can be used as a store of kinetic energy. Again, the rays of the sun warming unequally the equatorial and polar regions of the earth, gives rise to that circulation of the atmosphere which is wind, and is a source of kinetic energy or turning windmills.

All these sources of energy can therefore be traced back to the action of the sun, either now or in times long past; and all this energy is and has been conveyed to our earth by the undulating motion of that extremely rare medium to which we give the name of luminiferous ether.

The density of this medium is so small that the effect of its resistance on the motion of the planets, though accumulating since the time of their first discovery, has not become perceptible—that is, measurable with our means of observation; and the proof of its existence *might* have depended solely on the necessity of such a medium for transmitting the radiation of the sun. It may be a startling statement, but it is nevertheless undoubtedly true, that absolutely empty space, if such could exist, would be absolutely opaque, absolutely impervious to light and heat. But we are not left to inferences of this sort for proof of the existence of a medium pervading the interplanetary spaces. There is a member of our solar system, Encke's comet, whose time of revolution is moderate, and whose mass is so small that a resistance which produces no sensible effect on the motions of the larger masses of the *planets*, becomes sensible in its case. A slight progressive diminution in its period of revolution round the sun, which would be the direct consequence of such a resistance, has been observed.

We have, therefore, the direct testimony of this comet to the existence of that medium which we call ether.

It has been calculated from careful observations that the heat which reaches the earth from the sun in one year, including that intercepted by the atmosphere, would liquify a layer of ice 100 feet thick, covering the whole surface of the earth.

Now the heat requisite to liquify one pound of ice without producing any change in its sensible temperature is 142 of our heat units—*i.e.*, would cause a rise of one degree in 142 pounds of water, and each of these units is equivalent to 772 foot-pounds of work.

It would be useless for me to work out the result obtained by combining these numbers; the numerical expression of it would be so far removed from the largest numbers which the mind can comprehend, that it would convey no idea but a vague one of vastness; and yet we must remember that this vast amount of energy which reaches the earth annually is less than the two thousand millionth part of that which leaves the sun.

From what source this vast supply of energy which annually leaves the sun is derived is a most interesting and important subject of modern speculation; but this lecture has already reached a length which forbids me to enter upon it.

There is one other source of available energy upon the earth which, unlike those already enumerated, is not derived from the sun—viz., the energy of tidal action. The regular rise and fall of the tides is a source of energy which to us would be practically unlimited. There would undoubtedly be engineering difficulties to overcome before it could be rendered available; but if these difficulties at starting were once mastered, if the permanent works were once erected, the supply of power would be trustworthy, costless, and all but inexhaustible. From whence, then, is this energy of tidal action derived? That there is a vast annual waste in the vibrations communicated to the air as noise, and in the dissipation of the heat generated by the friction of the waves, is undoubted; and it is equally indisputable that from the motion of rotation of the earth this energy is derived. The earth making one rotation in a day forms a fly-wheel in which an enormous amount of energy is stored in the form of visible motion. The attraction of the moon in raising the tidal wave forms a sort of drag upon this motion, which, year by year, to an excessively minute extent diminishes its velocity of rotation, and produces a certain but imperceptible lengthening of the day. Since the time of rotation of the earth is the standard to which all our measures of time are referred, this lengthening of the day could not in itself be directly detected. But the time of revolution of the moon round the earth, as deduced from modern observations, shows a slight decrease when compared with that deduced from observations of eclipses

more than 2000 years ago. This phenomenon, known as the acceleration of the moon's mean motion, is capable of no other explanation than that it is an apparent diminution only, due to the lengthening of the time unit in which it is expressed. This loss of energy of rotation in the earth, due to the dragging action of the moon upon the waters of the ocean, is the source of that energy of tidal action to which I have directed your attention.

I have now enumerated the principal sources of energy available to us. There are several others which I have not mentioned, but they are so small in amount as to have no practical importance.

Two things, then, appear from the physical facts and laws which I have explained to you.

First, that energy is indestructible; that it requires an act of creation to increase or diminish the amount of it in the universe. The consideration of practical importance to us, however, is—that in the case of any limited material system—a machine for instance, the amount of energy which issues from it, either in the form of useful work done, or work wasted, or heat lost by radiation, or passing to bodies of lower temperature, the whole amount of energy so issuing must in the long run be numerically equal to the energy supplied to it from external sources. All attempts to evade this law, to construct machines which shall do work without a supply of power, or do more work than the equivalent of the energy supplied to them, must be failures. Let this truth be fully and firmly impressed upon you—that no amount of skill and ingenuity will enable you to produce work out of nothing; to construct or invent a machine which shall do more work than is done upon it, is as impossible as to create matter out of nothing; that the invention of a perpetual motion, or to speak more strictly, a perpetual source of power, must be ranked with the discovery of the philosopher's stone which turns all it touches to gold, or of the elixir of life.

Secondly, it appears from the facts and laws I have explained, that all the energy in the universe is slowly but surely distributing itself into a form in which it will be no longer available for doing useful work. Every change in the form of energy is accompanied either by the passage of heat from a body of higher to a body of lower temperature, or by the conversion into heat of some other form of energy, which after this conversion tends to dissipate itself by radiation.

That there is now going on upon the earth a consumption

and dissipation of energy greater than the supply annually received from the sun, is certain. Sooner or later our coalfields will be exhausted, and though that day may be far distant, it is none the less the duty of every one to use such skill and ingenuity as he may possess in economising the stores still left to us, and not to waste it in attempting what is impossible.

There is another point which I think must force itself on the attention of every one who has followed the explanations which I have attempted to give this evening—viz., the prominent place occupied by numerical relations. Every step, from the very earliest, presents itself in the form of an arithmetical operation, more or less complicated. All the laws which govern the conversion of one kind of energy into another are numerical laws—laws which can only be fully and properly expressed by mathematical formulæ. And so it is in every branch of physical science. All nature is governed according to weight and measure and number; and any one who desires to study natural laws, so as to really understand them, must come prepared to grapple with them in the only way in which they can be apprehended. A power of dealing with the relations of quantity as they present themselves at every step, in every branch of physical inquiry—reading certainly and accurately—is therefore a necessary preliminary to the commencement of such study; and it cannot be laid down with too much reiteration, that all study of physical science which is not based upon a constant reference of all phenomena to their quantitative relations is vague and valueless.

Let all, then, who commence the study of physical science in earnest, come to it with a firm determination to ask of every phenomenon the questions—How much? How long?

Knowing, as I do, how important it is to possess some mathematical knowledge, I cannot refrain from expressing my surprise that no provision has been made for giving mathematical instruction in connection with these technological courses. A worker at science, coming to the study without the power of calculation and expression which a knowledge of mathematics gives him, is like an artisan without his tools. It would be like attempting to erect such a building as that in which we are assembled with no other instrument than the flint axe of the pre-historic workman.

I take for granted that the object of the course of lectures established here is something more than the provision of an evening's amusement; that those alike who have organised these courses, and those who avail themselves of them, are

actuated by the single-minded desire to encourage the study of the laws of nature for the purpose of promoting the material well-being and industrial progress of the country; and I therefore make no apology for pointing out this most serious omission.

I cannot conclude better than by quoting the words of a veteran geologist upon this very subject—one who, though he has far passed the limit usually assigned as the life of man, is still in harness, doing his duty bravely. Speaking of the study of the laws of nature, he says:—"In this, as in every other field of labour, no man can put aside the curse pronounced on him—that by the sweat of his brow he shall reap his harvest. Before he can reach that elevation from whence he may look down upon and comprehend the mysteries of the natural world, his way is steep and toilsome, and he must read the records of creation in a strange, and to many minds a repulsive language, which, rejecting both the senses and the imagination, speaks only to the understanding. But when this language is once learnt, it becomes a mighty instrument of thought, teaching us to link together the phenomena of past and future times; and gives the mind a domination over many parts of the material world by teaching it to comprehend the laws by which the actions of material things are governed. To follow in this track, first trodden by the immortal Newton—to study this language of pure, unmixed truth, is to be regarded not only as your duty, but your high privilege. It is no servile task, no ungenerous labour. The laws by which God has thought good to govern the universe are surely subjects of lofty contemplation; and the study of that symbolical language by which alone these laws can be fully deciphered, is well deserving of your noblest efforts."

THE COMMON USES OF ASTRONOMY.

A LECTURE,

DELIVERED BY ROBERT L. J. ELLERY

(The Government Astronomer),

ON 20th OCTOBER, 1870.

THE subject of my evening's lecture—"The Common Uses of Astronomy"—was suggested to me by a member of the Commission as one likely to be of interest, more especially as it would include an exposition of some of the relations existing between scientific work and the application of its results to useful purposes, and concerning which it is believed a majority of the public are not yet fully informed.

I do not pretend to show you any *royal road* to astronomy; nor do I intend to enter any plea for the pursuit of a science the value and importance of which has been proved ages ago, and fostered and encouraged by every civilised nation of the earth; but I wish to show you *how far* and in *what way* astronomy is useful—nay, necessary, to all civilised communities, and how essential it is to commerce and settlement, as well as to the ordinary requirements of intellectual life.

2. To do this I shall confine myself to three principal instances—the use of astronomy in the determination, measurement, and maintenance of time; the use of astronomy in surveying; and astronomy as applied to the art of navigation.

3. To such a practical audience as is here present it will be needless to dilate upon the value and importance of the correct measure of time, the necessity for using every precaution for securing accuracy in the laying out of lands, or the paramount importance of the most extreme precision in navigation, where the error of a second or two in time, or of a few seconds in arc, may be the cause of shipwreck and loss of life and property. I shall therefore proceed at once to the first example of the common uses of astronomy.

4. The natural unit of time is the day, or a complete revolution of the earth on its axis, which occurs in 24 hours.

As the earth rotates from west to east, the sun and other heavenly bodies appear to rise in the east, pass across the heavens, and set in the west, and by marking the interval between the sun or stars attaining to any stated position with respect to the observer on one day and the next, we obtain our unit of 24 hours; this can be done most accurately by noting when the object is on the *meridian*, or due north and south: for instance, if you could get the side of a house nearly north and south, and note the moment a particular star passes the line of the wall to-night, and do the same to-morrow night, the interval would be 24 hours *star time*, or *sidereal time*, as it is called; if you observed the sun instead of a star, you would get 24 hours *solar time*. They would be different intervals, neither of which will quite correspond to the time used for the ordinary purposes of life, as I shall presently show you.

5. By methods analogous to, but more precise than this, the beginning and ending of a unit of time can be determined; the subdivision of the interval into smaller portions, such as hours, minutes, and seconds, is accomplished by various methods, the most usual consisting of *clocks* and *watches*.

6. The interval between the successive returns of a star to the meridian is called a *sidereal day*, and between the successive returns of the sun to the meridian is called a *solar day*. Now, on account of the earth's revolution round the sun, the latter apparently alters its position amongst the stars from day to day; indeed it appears to advance eastwards 59′ 8″ of arc with respect to the stars; hence the solar day is 3 minutes 56 seconds longer than the *sidereal* or *star day*, and a clock showing *star time* will only correspond with a clock keeping *solar time* once a year—that is, when the sun is in the vernal equinox.

7. The sun's apparent motion, moreover, is not quite regular —it is quicker when it is nearest the earth; the apparent solar days are therefore not equal throughout the year, differing sometimes as much *fifty-one seconds*. To avoid this difficulty, the average annual length of a solar day is taken instead of the true solar day, and called "*the mean solar day;*" this is the unit of time we use for the ordinary purposes of life.

8. The time obtained from an observation of the sun has to be corrected by adding to or subtracting from it a certain number of minutes and seconds, called the *equation of time*, the amount of which varies with the sun's distance from the earth. Sidereal time is only used in Observatories, or where astronomical observations are regularly made, in which cases it

is by far the most convenient time measurement; if we know the *true sidereal time* and the position of the sun (which is given very accurately in good almanacs), we can readily deduce the mean time of it.

9. Clocks and watches subdivide our unit, but those even of the best description are not perfectly reliable; they vary, from the many influences to which they are subjected—temperature, pressure of air, defective workmanship, and so forth, so that if set correctly at the commencement of a week, the most perfect astronomical clock made would not be so at the end; it gains or loses every day a small portion of time which is called its rate, and although in the best timepieces this rate may be moderately uniform, so that the amount of error at the week's end may be approximately ascertained, yet, to be certain, reference has to be made to our only perfectly reliable timepiece—the heavens.

10. The excellent clocks and watches now so common and so cheap perform the subdivision of our natural unit of time very satisfactorily, within certain limits, for the ordinary purposes of life; yet, however good, they have to be set occasionally, though not perhaps so often as the celebrated watch of Capt. Cuttle, which, as he said, "Put it back half-an-hour every morning and about another quarter towards the arternoon, and it's a watch that'll do you credit."

11. When we find our clocks or watches have accumulated their rate so as to be minutes fast or slow, we adjust them by the most reliable clock within reach—the Post-office clock, the railway clocks, or the clocks exposed in the windows of our principal watchmakers—for these are usually supposed to be correct, and ought to be so by continual reference to the Observatory time, and *act as liberal retailers of the result of astronomical observation.*

12. There are many methods by which the time can be ascertained by astronomical observation—in some cases from the sun, in others from the stars—every one of which, however, requires some preliminary conditions to be fulfilled. One of the simplest cases is that of the sun-dial. The requisite conditions here are—first, that the dial shall have been properly constructed, to do which it is necessary to know the latitude of the place for which it is intended—this requires the aid of astronomy; then it must be placed with the Gnomon, or twelve-o'clock line, precisely in the astronomical meridian—a process requiring another astronomical operation; and when all this is secured, unless the dial be of very large

dimensions, the true time cannot be obtained within, say, half-a-minute. The time shown by a sun-dial is *apparent*, or *solar time*; to bring this to *mean time*, we must apply the *equation of time*. The shadow is right, however, with *mean time* on four days of the year—about the 15th of April, the 15th of June, the 1st of September, and the 24th December. A table of the *equation of time* is often engraved on good sun-dials, with the words opposite particular months, "clock fast of sun," or "clock slow of sun;" the former showing that the "equation" must be added to the dial indication, and the latter, subtracted from, to get *clock time* or *mean time*.

14. Another common method of obtaining time is by observing the altitudes of the sun or of a star, when well east or west, by means of an angle-measuring instrument, such as a sextant or theodolite. This requires that the position of the star or sun (that is, its right ascension and declination) and the latitude of the place of observation be accurately known, involving, as before, preliminary astronomical observations. From an observation of this kind the time, either sidereal or solar, can be deduced by calculation, involving spherical trigonometry.

15. The most usual method, however, and almost the only one used in Observatories, is by observations of the instants at which the sun or stars pass the meridian, by means of a transit instrument and astronomical clock, the precision attained depending on the dimension and quality of the instrument and expertness of the observer.

16. A transit instrument consists of a telescope rigidly fixed to a cross axis terminating in pivots, which rest in bearings. The bearings are fixed horizontal one with another, and due east and west, so that the telescope can revolve in a vertical circle north and south on the meridian.

17. Here is a small portable instrument of this class. This is of small dimensions, and intended for use in surveying operations. In Observatories they are generally much larger, and mounted with the greatest possible stability on massive stone pillars. With a transit instrument thus mounted truly in the meridian, the moment at which a star or the sun passes the meridian can be observed with great accuracy. To obtain the greatest precision possible, the passage over several of the wires is usually observed and combined into one mean result.

18. It is necessary in transit observations that the times of the star or sun passing the wires, as shown by a good clock

or chronometer, should be noted. This is accomplished by having a clock with audible beats near the observer, so that he can count the vibrations of the pendulum as he watches the star crossing the field of his telescope, passing successively the several wires in the eye-piece; the exact beat and part of a beat of a pendulum of each of these occurrences is noted, and he has then the necessary observation for ascertaining how much too slow or too fast his clock is.

19. But this is only supposing all the preliminary conditions have been satisfied, the most important of which are that the true *R.A.* and *declination* of the stars observed be known, the centre wire of the transit instrument be truly in the meridian or the deviation therefrom precisely known, and the pivots of the cross axis be truly horizontal.

20. The latitude is known from previous astronomical observations; the positions of some hundred and fifty stars are now known with very great exactitude, and are tabulated in the Nautical Almanac for every ten days.

21. To satisfy those conditions relating to the position of the instrument, special observations besides those for obtaining the time itself are required. The transits of several stars situated in different parts of the heavens have to be observed to know how much the telescope deviates from the true meridian; the horizontality of the pivots or departure therefrom must be measured by a delicate spirit level, or by other means equally tedious, so that before you can use the times of the transit of the star for finding the error of your clock, you must make many more observations to determine how much they must be corrected for deviation of the instrument from its required position. These operations have always to be gone through, for no matter how solidly the instrument is mounted, or how massive the piers on which it rests, it can seldom be got absolutely correct, nor does it remain the same from day to day. If the piers were as massive as the great pyramid, it would be found by careful observation that they were not motionless, and movements so minute as to be perfectly inappreciable to any terrestial measure become large and serious in the case of astronomical observations.

22. The maintenance of true time is the first and the most important work in an Observatory, and the means of doing so are as essential to it as capital to a banking business. The clocks have to be the best that can possibly be made, yet for all that they must not be trusted, but called to task on almost every fine night by means of the stars.

23. Of late years the mode of making transit observations has been much improved by the application of the electric telegraph. Instead of the observer listening to the beats of the clock as he watches the passage of the stars through his telescope, an apparatus called a *chronograph* is used, which does all the counting and writing down for him. It consists of a kind of telegraph instrument, with a moving strip of paper or revolving cylinder covered with paper, upon which a pen or pencil is made to mark by means of a magnet worked by galvanic currents. The clock sends a current every tick or vibration of its pendulum, which causes a mark to be made on the paper as it passes under the pen at an uniform rate by means of clockwork—counts seconds on the paper, in fact—while the observer by touching a key transmits a current at the instant the star passes each of the wires in the telescope, so that the clock's marks being distinguishable, the position of the mark made by the observer indicates with the greatest nicety the time of observation, much more accurately and with far less trouble than by the method of listening to the ticks of the clock.

23. It is very seldom that observations of the sun are made for the determination of time in an Observatory; stars are nearly always used for this purpose.

24. By these means, therefore, the astronomical clock is kept under a strict watch, and its error and rate obtained from day to day, so that the exact mean time is known at any moment. (By ERROR, I mean the amount it is wrong at time of observation, and by its RATE, the amount the clock loses or gains in 24 hours.)

25. We now come to ascertain how this is made use of for public purposes, and I do not think I can do better than tell you how it is done in our Observatory, as that is a fair sample of how it is usually done. First and foremost, the maritime community are considered—they require to get the mean time regularly and with the *greatest precision* whilst in port, in order to ascertain the errors and rates of their chronometers—for on these beautiful little instruments depends in a very great measure the safety of a ship on a long voyage. For this part of the public every facility is afforded; they have access to the Observatory at all times; can get their chronometers rated and instruments tested free of cost; and time signals are given every day, except Sundays, by which they can obtain the desired mean time.

26. Chronometers are generally set to Greenwich mean

time on board ship; this we know is 9h. 39m. 54·8s. behind Melbourne time, being the exact difference of longitude between the two places. The time signals are given at 1 o'clock, Melbourne time, which corresponds to 15h. 20m. 5·2s. Greenwich time, or 20 minutes past 3 in the morning.

27. There are time-balls at Melbourne, Williamstown, and Geelong, which are connected by telegraphic wires with the Observatory. Every day, a few minutes before 1, these lines are left clear for sending time signals. At 3 minutes to 1 o'clock one of the Observatory clocks is put in connection with all the telegraph lines in the colony, and its ticks are heard in every office. At 1 minute to 1 the clock is changed for another, which sends only certain ticks, and ends with five consecutive ones, the last of which is 1 o'clock mean time, within a 20th of a second. At each of the time-balls a little indicator is placed near to the discharging trigger, which is watched by the person who drops the ball, and the trigger is pulled exactly as he sees the last of the five vibrations or ticks. The true Melbourne time is also thus transmitted to every telegraph station in the colony.

28. In order that captains of ships and others who wish to get rates of chronometers may do so with the greatest possible precision, arrangements are made that the time-ball at Williamstown, in dropping, telegraphs back to the chronograph at the Observatory that it does so and at what instant, so that if any error is made, however small, in dropping the ball, the amount is notified in the shipping news in the next morning's papers; the small amount to be added to or taken from the time of ball drop to make it true time is thus supplied.

29. The clock that sends the telegraph signals for the time-balls must, of course, be perfectly correct at 1 o'clock, and as the best clocks seldom remain exactly right from day to day, a means of setting this one so is adopted. At 12 o'clock its error to the $\frac{1}{100}$ of a second is ascertained by comparison with the transit clock, and a small weight is added to or taken from the pendulum, without in any way stopping or interfering with its going. The weight is so regulated that it causes the clock to gain or lose $\frac{1}{10}$ second for every three minutes it is on or off; it is thus made perfectly correct for the time signals at 1 o'clock.

30. The Post-Office Clock can be connected by wire with the Observatory at any moment, and a mechanism is provided in the works by which a galvanic signal can be transmitted every half-minute. Each day, about noon, the clock is connected

with the wires leading to the Observatory and the signals received on the chronograph; the error is thus ascertained to a tenth of a second, and is notified in the next day's papers—it generally appears underneath the Observatory notices in the shipping columns.

31. For several years past a method of maintaining true time in large towns by keeping clocks controlled by a weak electric current, so as to be all exactly uniform with the clock that sends the current, has been gradually coming into use. The method is known in England as "Jones's method," being patented by Mr. Jones, of Chester.

32. The clocks to be controlled have the bob of the pendulum made of a hollow coil of insulated wire; one end of this coil is connected with a telegraph wire led from the controlling clock, the other is connected with the earth, or goes on to the next clock to be controlled. Two permanent magnets are fixed so that the hollow pendulum coil of the clocks to be controlled encloses the ends of them at each vibration. The controlling clock sends a pulsation of a weak galvanic current along the clock wire every second, but alternately positive and negative—positive for the even second, and negative for the odd one. The pendulum coil becomes to all intents and purposes a magnet at each pulsation, but with poles reversed every second. The permanent magnets are placed with their north poles opposing one another, so that by the repulsion of similar poles and the attraction of dissimilar ones the pendulum is driven to arrive at the end of each vibration with its south side to the north pole of the magnet. By this means the clocks that are strung on to the wire, however bad otherwise, are forced into unison with the controlling one; and if the controlling one be kept right, like the time-ball clock at the Observatory, any number of clocks in a town attached to the clock wire will be compelled always to indicate the same time to a second.

33. This plan is now extensively used in London, Edinburgh, Glasgow, Liverpool, and other large cities. The telegraph companies erect a clock wire from the Observatory of the city and lead it throughout the town like a gas or water main, only usually above ground instead of beneath. Any one who wants "*Time supply*" laid on to his clock can have it for from £1 to £5 per annum.

34. This method is already partially adopted in Melbourne; many months ago the telegraph authorities erected a time wire

from the Observatory into town, and Mr. Gaunt, of Bourke-street, was the first to avail himself of *time supply* for his large clock in his window at the corner of the Arcade, which is thus kept in perfect unison with the mean-time clock at the Observatory, and has never been a second wrong since it was first got in working-order, now several months ago.

35. The several clocks about the platform of the Hobson's Bay Railway Station will shortly be controlled from the Observatory in the same way, and it is to be hoped for the sake of public convenience that every clock exposed for reference will before long be similarly connected. *Any old rattletrap of a clock with a good face* does as well as the best, the cost of the pendulum and magnets is trifling, and the rent for time supply is as easy as in Glasgow or Liverpool.

36. Having so far endeavoured to explain to you one of the "Common Uses of Astronomy," the mysteries of the dissemination of true time, I shall now proceed to consider the uses of astronomy in surveying.

37. We must start with a clear definition of what I mean by surveying; for there are so many operations that come under this title with which astronomy can have directly very little to do—directly I say, for it is hard to say with what operations astronomy is not *in*directly concerned, from the navigation of a navy down to the laying of a course of bricks or stones in a building.

38. The surveying I refer to is that which deals with marking out land for settlement or sale, with obtaining maps of a country, or with laying out roads and railways.

39. One of the first operations requisite in making a survey is that of determining the direction of the meridian; for it is very essential that all lines by which a survey is bounded should have some direct reference to a standard and universally adopted direction. This direction is north and south, or the meridian; in other words, the *bearing* of every line must be determined. This is requisite on several accounts: If land is sold it must be accompanied by a deed setting forth the area, dimensions, and *bearings* of the boundary lines; and if the land be not occupied or fenced in soon after the survey is made, the pegs put in and the trenches marked by the surveyor become obliterated, and the only way to recover the boundary is by reference to the terms of the deed, to the bearings and lengths of the lines. If the bearings have been given with reference to the true meridian, the recovery of the lost marks is readily accomplished.

40. The simplest of all methods of obtaining the bearing of a line is by means of the magnet or compass, and in the early days most of the surveys were made dependent on the compass—even now it is still in use in some classes of surveying. In such cases the boundaries are described as bearing so-and-so, magnetic. *Unfortunately,* however, the magnetic needle is subject to several, and often unexpected, variations, which render it a very unsafe guide for direction where so much accuracy as is necessary in surveying is required.

41. In the first place, the needle seldom points to the North pole—its direction varies in different parts of the earth; in some places it points many degrees away from the meridian—this deviation is known as the "variation of the compass," or the magnetic declination; it is ascertained at any time by finding the difference between the true north direction and that indicated by the magnet by astronomical observation. If a surveyor, therefore, determines the variation on the spot, and then performs his survey by the help of the compass, he corrects all his bearings, making them *true* instead of *magnetic*, and his work will be by far more reliable than if he gave his bearings from compass indications alone. But there are yet other grave objections to the use of the compass in surveying; not only is there the variation, but a variation of the variation constantly going on, and this secondary variation is both periodic and occasional.

42. In this part of the world, for instance, the variation is now increasing every year by about one minute of arc. This change is called the annual variation. Every day the needle goes through a considerable change, commencing to point more easterly about nine in the morning, increasing till about two in the afternoon, and then falling back again about six or seven in the evening. This is known as the *diurnal variation*, and amounts to $11'$ in winter, and $15'$ or $\frac{1}{4}$ of a degree in summer, amply sufficient to render a survey by compass carried on throughout a whole day very queer indeed.

43. During magnetic disturbances of the earth the compass may change many minutes in an hour, and frequently deviates on these occasions nearly a degree and a quarter.

44. Again, the needle is largely influenced by the presence of many rocks, especially those containing iron, and in surveying over some geological formations the compass becomes perfectly unreliable. I know one or two localities where the attraction is so great that the needle will point to every point of the compass as you go in a circle covering an area of about

a mile; within these circles are strata of magnetic rocks. So, you see, if a surveyor trusts to his compass alone for accurate direction, the probability is that he is trusting to a broken reed, and is investing errors at compound interest, which eventually lead to doubt, trouble, and often expensive litigation.

45. For, suppose farms of a mile square each had been laid out in 1850, east and west of each other by compass survey. The one owning the eastern farm fenced in his ground while the marks were there, the other not till 1870, when he would lay out his boundary according to his deed, but would find his neighbour's fence projecting some twenty feet or more into his ground; the fact would be that the variation had increased year by year till his north and south boundary no longer coincided with what was laid out twenty years previously. Of course such a thing could not be tolerated, and our two farmers go to law, and probably spend a hundred times the value of the ground at issue before they are contented.

46. These are simple samples of what has happened to an enormous extent in America and Canada, and even to some extent in these colonies, where it is not at all improbable many more cases may eventually rise up among our old compass-made surveys.

47. The only remedy for all this is to fall back on astronomy, as all good surveyors do; they do not trust to their compasses except for very small intervals; they determine the *true* bearing of one line, and lay off the rest with reference to it by their theodolites. The true meridian is determined by astronomical observations of the sun or stars made with the theodolite, and several methods are adopted, depending upon whether they know the true local time and latitude or not.

48. In surveys made for mapping a whole country or for laying out a large territory, the necessity and importance for using astronomy is far greater, and no reliable work could be done without it. The great trigonometrical survey of England, Scotland and Ireland, the great military and Cadastre surveys of the European Continent, and the survey of the public lands and the coast survey in the United States, are all conducted upon an astronomical basis, as is also our own Geodetic survey, now being brought to a close.

49. The Geodetic survey comprises two modes of operation —the one applicable to laying out large areas of land enclosed

by geographical meridians and parallels one tenth of a degree apart, and containing about 25,000 acres; the other to the correct mapping of the colony with all its existing surveys and features placed on the maps as they *really exist on the ground.*

50. The first method could not be carried out without constant appeal to the stars for true direction, latitude, and longitude; the second requires that the exact astronomical bearing, as well as exact length of every side of the numerous triangles which now cover the whole colony with a network should be most carefully ascertained; indeed, all large surveys of this kind are from beginning to end almost entirely an astronomical operation.

51. The observations most required in these surveys are for obtaining the azimuth or true direction, time at place of observation, latitude of place, and for elevation above sea level; they involve the use of transit instruments, chronometers, and instruments for measuring vertical angles, such as the altazimuth and zenith sector.

52. We now come to our third case of the common use of astronomy, namely, its use in navigation; and in this art, as in surveying, we shall find that astronomy is all important.

It has often been a matter of surprise to many how the early navigators did so well and ventured so far with their compasses and limited means of reference to the heavenly bodies as they then possessed—it only shows the truth of the old nautical maxim that "Lead and Look out" are the safest navigators; but the invention by Huygens of his marine pendulum watches in 1664, afterwards perfected by Harrison in 1749; the introduction of Hadley's Quadrant, now developed into that beautiful instrument the sextant; and the increased knowledge of the places and movements of the heavenly bodies, have brought the art of navigation to almost perfection in skilled hands.

53. To give you an adequate idea of the uses of astronomy in navigation, I propose to take the case of a ship on a long voyage—say from Melbourne to London, completely provided with all the necessary modern nautical astronomical instruments, compasses, chronometers, sextants, &c. Until he loses sight of land the various points and headlands afford the navigator ample guide as to his position and course, but as he gets farther to sea the course (or direction) by compass is carefully observed from time to time, or the steersman is ordered to keep in a certain course. This is noted on a log-slate, with the

time at which she commenced to sail on this course, and every alteration of it is entered with the times at which they are made; the "log" is cast very frequently to ascertain the speed with which the vessel progresses—this is also entered on the log-slate. At the end of 24 hours the "day's reckoning" is made up thus:—If the entries on the log-slate state that from 8 a.m. till 8 p.m. the course was S.W. by compass 5 knots per hour, from 8 p.m. to 4 p.m. S. by W. 4 knots, and from 4 p.m. to 8 a.m. S. 7 knots, the ship has travelled 120 nautical miles, but not in a straight course. The object is to find the ship's position. At starting her latitude was 39° S. and 139° East longitude; now, by correcting the compass course by the known variation, and computing the difference of latitude and longitude of each point where the course was altered, multiplying the number of knots by the sines and co-sines of the different corrected bearings, the position of the ship, or its new latitude and longitude, are known roughly—this is called navigating by "*dead reckoning.*" This process if carefully carried out frequently gives the position very close indeed; but an unfortunate circumstance called leeway, as well as the action of ocean currents whose rate and direction are not always precisely known, impart in most cases considerable doubt into the method, and navigators become very anxious if through a succession of cloudy weather they are prevented from appealing to the stars to verify the position given by dead reckoning.

54. The leeway is a kind of drifting motion at right angles to the course, which most ships are subject to to some extent, but some much more than others. Currents often tend to increase the leeway, if the direction of their set is against the weather side of the ship. They may also either retard or accelerate a ship's speed without the log giving evidence of it. For in ordinary circumstances, however rough the sea, the actual translation of water, or of an object placed in it, is very small. In a heavy sea even, with no current, the log would indicate directly the speed of the ship; but suppose the current to coincide with the ship's course, the water itself progressing onward carries both the log and the ship; the indication is therefore the rate the ship is driven in excess of the rate of the current.

55. Leeway cannot be accurately measured, and the allowance for it is necessarily always to some extent guess-work.

56. But supposing at the end of twenty-four hours, at eight in the morning, the weather be fine, the captain brings up his

sextant and "takes a sight"—observes the altitude of the sun above the horizon, in fact; at the moment he brings down the sun's reflected image to touch the sea horizon he calls out to an officer placed at the chronometers in the cabin to "mark" or note the time shown by them—he usually makes three or five or more observations of this kind. Now by means of the observation and the latitude of the ship, which we will suppose to be known, and the tables of the sun's place given in the N.A., he computes the mean time at ship. The error and rate of his chronometer, which shows Greenwich time, has been carefully ascertained by means of the time-ball while in port; by accounting for these, then, he knows by his chronometer the exact Greenwich time at the moment of his observation; the difference of this and the time he deduced from his observation gives him at once the longitude of the ship by observation. At noon, as the sun approaches the meridian, he takes his sextant again and observes the sun, keeping its image reflected from the index-glass coinciding with the horizon by moving the index until he finds that the sun has attained its greatest altitude; he finds what this altitude is by reading his index, and with this altitude and the declination of the sun as given in the N.A. he obtains the latitude of the ship.

57. By comparing the latitude and longitude by observation with that by dead reckoning, he finds out how closely his ship has worked, but the place by observation is in nearly every case accepted as the true one. Dead reckoning is only accepted as an alternative, and then with great reserve, when no observations can be taken.

Suppose now the chronometers were to stop or otherwise go wrong, or any doubt arise in the captain's mind about their rate, he has to make another and more elaborate appeal to the heavens, and in this case the moon must be one of the bodies observed; he must in fact take a "lunar," to determine what is the Greenwich time independently of his chronometer.

59. This observation consists of measuring with the sextant the angular distance between some planet or bright and well-known star and the moon's bright limb—observing also their altitude above the horizon, as well as the local time of observation. From these data he computes by a somewhat laborious calculation, and by aid of the Nautical Almanac again, the Greenwich time at which this position of the moon would occur. He thus obtains his "Greenwich time," and ascertains how far his chronometers are wrong. Of course, if they have stopped, he sets them going before he takes his "lunars,"

unless something radically wrong has taken place with the mechanism. The stopping of a chronometer is not, however, a very common occurrence on board ship. Careful navigators are in the habit of taking lunars frequently, so as to keep a watch on the chronometers; but the latter are now so good and reliable that taking "lunars" is, I fancy, rather the exception than the rule.

60. Ships' compasses often go wrong, more especially in iron ships. Here, again, the only help is in astronomy. The latitude of the place being known, and the declination of the sun being given in the Nautical Almanac, its bearing can be easily computed. Now by observing with a compass provided with sights, and called an *azimuth compass*, the magnetic bearing at any moment, the difference between it and the computed bearing gives the error of the compass. In iron ships this observation has to be repeated constantly.

61. There is scarcely an occasion upon which an astronomical observation is more valuable, such a *Godsend*, as when a ship after a long voyage approaches land during cloudy or thick weather. If the captain cannot get his sight, he and his officers are anxious—watching for signs of land, listening for the boom of the surf or the splash of breakers; but if he succeeds he calculates his position, a load is off his mind, he rubs his hands, and says "We'll make the Lizard at daylight."

62. I have now come near the end of my task, and I trust I have been able to convey to you some knowledge of the "Common Uses of Astronomy" as applied to the several branches of science I have referred to. Before concluding, however, I have a few words more to say. I have spoken throughout my lecture of astronomical information always at hand, by which the results of observations can be arrived at; the "position of over 150 stars;" the sun's place in the heavens, his declination and right ascension from day to day; the moon's position and distance from planets and certain stars; the movements of all these bodies, and so forth. I have spoken of all this information as being available in tables, almanacs, and, *par excellence*, in the Nautical Almanac, and it may well be asked whence is this information obtained? how is all this supplied? who supplies it? It is supplied by the National Observatories of the world, and the patient, plodding observers therein; it is being supplemented and rendered more precise and accurate every year by dint of continuous and careful observation and tedious calculation. To

supply it is the principal object of Observatories maintained, like ours, at the national expense.

63. The position of every star given in the Nautical Almanac has been measured thousands of times and is yet being measured and measured again, for you must know that although they are called *fixed stars*, in contradistinction to the planets, yet they are by no means fixed with respect to us, nor yet in reality; they change their places by reason of the irregularity of the earth's annual motion, and many of them, too, have proper motions of their own. To measure these motions requires constant and unremitting observations.

64. In his remarks upon the occasion of the publication of the British Association Catalogue of Stars, Sir John Herschell says—"The stars are the landmarks of the universe; and, amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in His works. It is indeed hardly possible to over-appreciate their value in this point of view. Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him—the same for ever and in all places; of a delicacy so extreme as to be a test for every instrument invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock as for conducting a navy to the Indies; as effective for mapping down the intricacies of a petty barony as for adjusting the boundaries of transatlantic empires. When once its place has been thoroughly ascertained and carefully recorded, the brazen circle with which that useful work was done may moulder, the marble pillar totter on its base, and the astronomer himself survive only in the gratitude of posterity: but the record remains, and transfuses all its own exactness into every determination which takes it for a ground-work, giving to inferior instruments, nay, even to temporary contrivances and to the observations of a few weeks or days, all the precision attained originally at the cost of so much time, labour, and expense."

65. After centuries of observation the true position and movements of only a comparatively few of the heavenly bodies are yet known. The best tables of the position of the moon, for instance, are yet far from perfect, and were but a few years ago liable to large errors.

66. I recollect that when the position of Burke and Wills' camp on the shores of the Gulf of Carpentaria was calculated at the Observatory from the lunar observations poor Wills took there—the longitude was computed from the places of the moon as given in the Nautical Almanac, but subsequently corrected from an actual determination of the moon's place—the difference in the position was 25 miles; in fact, the error of the moon's place as given in the Nautical Almanac gave rise to an erroneous result in longitude equal to 25 miles. This would be a serious amount to a captain of a ship with unreliable or broken-down chronometers!

67. Some years ago the "tables of the moon" were corrected in accordance with more recent observations, and although they are yet far from perfect, they no longer contain such errors as I have referred to.

68. Every astronomical observatory supported at the national cost has a twofold function to perform; it has to provide for local and immediately utilitarian purposes, some of which I have explained—it has also to take its share in the great work of watch and measurement of the heavenly bodies for perfecting our knowledge of their position and movements which is being steadily prosecuted throughout the Northern, and more sparingly in the Southern hemisphere.

69. Our Observatory has been so well furnished and so liberally supported by our Government and Legislature, that it may also be asked—What has been done?—is our well-found astronomical establishment standing still in the world?

70. You will now know something of what it does amongst yourselves, but I have not spoken of what it has done and is doing towards supplying its share of the world-wide requirements of astronomy. The various volumes which have issued containing the results of the work for this purpose are now spread amongst astronomical and scientific bodies and individuals all over the world, and are admitted to be the most valuable catalogues in existence of the Southern heavens. In support of this assertion I would beg to quote from a scientific German periodical:—

71. "The observation-series at the Observatories of the Southern hemisphere hitherto available are not only in smaller numbers and to a smaller extent, but they are also mostly executed with far less perfect instruments than those which have been made at the observatories of the Northern hemisphere. It follows, therefore, immediately, that our knowledge of the positions and motions of celestial bodies of the Southern

heavens ranks behind those which we have obtained with regard to stars situated more northerly and accessible to European observers. The necessity is all the more felt, therefore, to examine the already published star-catalogues of the Southern heavens with reference to their reliability, in order to ascertain their greatest possible value for astronomy; for this reason I beg to draw the attention of the readers of this periodical to an observation-series which as it appears may be numbered among the most excellent which have reference to Southern stars, and which—if an opinion may be formed of their accuracy by the consistency of the observations—may be ranked by the side of the better of the European observations. It is the series of observations which has been executed at the new Observatory, Melbourne, during the years 1863 to 1865."

72. This will be in degree as satisfactory to you as it is to those more closely concerned, and I am sure you will all join me in the hope that Melbourne will be as much honoured among the older nations of the earth for her position and contributions in science, arts, and letters, as she is celebrated for her great and growing commerce.

THE APPLICATION OF PHYTOLOGY

TO THE

INDUSTRIAL PURPOSES OF LIFE.

A LECTURE,

DELIVERED BY F. VON MUELLER, C.M.G., M.D., Ph.D., F.R.S.

(Comm. Ord. Santiago, Kn. of Orders of Austria, France, Prussia, Italy, Wurtemburg, Denmark, Mecklenburg, Gotha; Government Botanist for Victoria, and Director of the Botanic Gardens of Melbourne),

ON 3rd *NOVEMBER,* 1870.

CALLED upon somewhat suddenly to choose the theme for the discourse of this evening, I made my choice unguardedly. I anticipated in my thoughts how, during the intended instructive recreation of this hour, the bearings of intimate botanic knowledge on many an industrial pursuit might readily be demonstrated by some impressive facts. But on reflection, I saw myself at once surrounded by so varied and bewildering a multitude of objects, that to do justice in a few words to my theme became a hopeless task. But while I offer this mere introductory address for a series of lectures in the phytologic section of this institution, we might learn by a rapid glance over an area of knowledge singularly wide, that only

The Lecture was illustrated by large wall paintings of "Eucalyptus amygdalina" (the most gigantic tree anywhere in British territory), of "Brachychiton Delabechei" (the Bottle-tree of East Australia), of "Cereus giganteus" (the huge Cactus of New Mexico); also by numerous Vegetable Chemicals, and samples of Raw Material; by about one hundred different kinds of Paper, from various substances; by microscopic drawings of Starches; and by a host of living Plants of medicinal, or economic, or industrial value.

through many successive discourses, explaining subjects in detail, the student can become aware of the importance of phytologic knowledge in its relation to the industrial purposes of life. In all zones, except the most icy, mankind depends on plants for its principal wants. For our sustenance, clothing, dwellings, or utensils; for our means of transit, whether by sea or land; indeed, for all our ordinary daily requirements, we have to draw the material largely—and often solely—from the vegetable world. The resources for all these necessities must be—it cannot be otherwise—manifold in the extreme, and singularly varied again in different climatic zones, or under otherwise modified conditions.

To render, therefore, these vegetable treasures accessible to our fullest benefit, not only locally but universally, must ever be an object of the deepest significance. Increasing requirements of the human races and augmented insight into the gifts of nature render now-a-days quite imperative the closest appliances of science to our resources and our daily wants.

"*Omnis tellus optima ferat!*" has become the motto of our Acclimatisation Society; or let me quote from Virgil:—"*Non omnis fert omnia tellus, hic segetes, illic veniunt felicius uvae.*" Striving to unite the products of many lands, it suffices for us nowhere any longer to discriminate among these resources with merely crude notions; but it becomes necessary to fix accurately, also, as far as plants are concerned, their industrial value, trace their origin, test their adaptability, investigate their productiveness, durability, qualities; and to reduce all these inquiries to a sound basis by assigning to any species that position in the phytologic system by which it can be recognised by any one in any part of the globe. When the wants of phytography are satisfied we have to call to aid chemistry, therapy, geology, culture, microscopic investigation, pictorial art, and other branches of knowledge, to illustrate the respective value of the species, and the degree of its importance to any particular community. But in the discussions of one evening we can do no more than to touch succinctly only on a few of those vegetable objects most promising to our own colony for introduction, or most accessible among those indigenous here; we may glance on them, also, with a view of learning how their elucidation might practically be pursued, and the knowledge thus gained be diffused. To aid in the latter aim the phytologic section in the Industrial Museum is to be established; of the requirements of this section I shall say a few passing words.

The products and educts of the vegetable world are immense; any display of them in the order of science, as intended for this museum, must carry with it a permanency of impressive instruction which any other modes of teaching, sure to be more ephemerous, fail to convey. But these efforts at diffusing knowledge should be seconded by means not inadequate to a great object, and should be worthy of the dignity and name of this rising country. Who would not like to see the best woods of every country stored up here in instructive samples —nearly a thousand kinds alone to choose from as far as our continent is concerned? Who would not wish to have here at hand for comparison the barks, exudations, grains, drugs, as raw material? Who would not desire to have ready access to a series of oils, whether pressed or distilled, whether from indigenous or imported plants? Who would not have it within his power to compare the starches, dyes, casts of our luscious fruits, or the paper-material, tars, acids, coals of various kinds, fibres, alkaloids, and other medicinal preparations from various plants?

Why not place here a series of all the weapons and implements, traced accurately to their specific origin? From such even in many instances we have learnt, through keen observations of the first nomadic occupants of the soil, the use of many kinds of wood. All these objects, crude or prepared in the multitudinous way of their adaptations, ought to be accompanied wherever necessary by full explanatory designations, microscopic sections, and other means of elucidation; while the periodic issue of descriptive indices, detailing still more copiously the derivation, uses, preparation, and monetary value of such objects, will enable us to serve the full intentions for which this museum section has been formed.

Lectures, however valuable, demonstrations, however instructive, cannot alone form the path of extensive industrial education; most minds indeed prefer to dwell tacitly on the objects of their choice, and muse quietly about the adaptability of any of them for operations or improvements in which they may be specially interested.

How many inventions have received their first impulse from an institution such as we wish to form! Investigators, eminent in their profession, will doubtless unite here, sooner or later, to bring to bear the sum of their knowledge, earned by a lifelong toil, for giving vitality to that information which is to enter guidingly into the ordinary purposes of life. Thus, the happiness and prosperity of our fellow-men should be

enhanced and exalted, and one of the loftiest objects of our striving after truths be fulfilled.

But the unassuming worker, conscious how far his own honest intentions advanced beyond his best results, may well exclaim with Moore, in his soft melodies:—

> "Ah! dreams too full of saddening truth,
> Those mansions o'er the main
> Are like the hopes I built in youth,
> As sunny, and as vain!"

Let us first take a glance at one of our innumerable forest glens. We see in the deep rich detritus of rocks and fallen leaves, accumulated in past centuries, some of the grandest features of the world's vegetation. Fern trees* rise, at least exceptionally, to a height of eighty feet; higher, therefore, than any in other parts of the globe, unless in Norfolk Island. Mammoth-Eucalypts abound, having in elevation rivals only in the Californian Sequoia Wellingtonia; we may, indeed, obtain from one individual tree planks enough to freight almost a ship of the tonnage of the "Great Britain." Todea Ferns, now sought in trade, occur in these recesses, weighing, deprived of their fronds, almost a ton; and if the Xanthorrhœas do resemble, as popularly thought, our once spear-armed natives, then the Todea stems bear certainly as justly a resemblance to large black bears, as has been comically contended. The Fan Palms,† though only occurring in East Gipps Land, within our territory, rank among the most lofty of the globe, though also among the most hardy. All this in our latitude seems astounding—but more, it demonstrates also great riches; and I allude to it here only because I wished to show how a vegetation so prodigious points to the facilities of a natural magnificent industrial culture. The complex of vegetation is always an indicator of the soil and climate; as such alone, plants deserve close study. In this instance it reveals untold treasures, and yet without phytographic knowledge they could never be understood, nor any intelligent appreciation of them be conveyed beyond the locality.

But can this grand picture of nature not be further embellished? Might not the true Tulip tree, and the large Magnolias of the Mississippi and Himalaya, tower far over the Fern trees of these valleys, and widely overshade our arborescent

* Alsophila Australis, R. Br.
† Corypha (Livistona) Australis, R. Br.

Labiatae?* Might not the Andine Wax Palm, the Wettinias, the Gingerbread Palm, the Jubaea, the Nicau, the northern Sabals, the Date, the Chinese Fan-palms, and Rhapis flabelliformis, be associated with our Palm in a glorious picture? Or turning to still more utilitarian objects, would not the Cork tree, the Red Cedar, the Camphor tree, the Walnuts and Hickories of North America, grow in these rich, humid dales, with very much greater celerity than even with all our tending in less genial spots? Could not, of 400 coniferous trees and 300 sorts of oaks, nearly every one be naturalised in these ranges, and thus deals, select tanning material, cork, pitch, turpentine, and many other products, be gained far more readily there than elsewhere in Victoria, from sources rendered our own? Ought we not to test in these valleys how far the Sisso, the Sal, the Teak, may prove hardy, and as important here as our Blackwood and Eucalypts abroad? Or shall I enumerate all the ornamental woods for furniture, machinery, instruments, which from an endless array of genera and species might be chosen as introducable indeed from most lands; many of these, perhaps, to find an asylum in our mountains before—like in St. Helena and other isolated spots—the remarkable and endemic trees are swept by man's destructive agency from the face of the globe? Shall I speak in detail of the trees which yield dyes, and many medicinal substances? If the Turkey Box tree should continue the best for the wood-engraver, it would in these valleys assume its largest dimensions. I do not hesitate in affirming that out of about 10,000 kinds of trees, which probably constitute the forests of the globe, at least 3000 would live and thrive in these mountains of ours; many of them destined to live through centuries, perhaps not a few through twice a thousand years, as great historic monuments. Within the railway fences, hitherto in this respect unused, trees might be raised as material for restoring locally the sleepers, posts, and rails, prior to their decay. The principles of physiology, the revelations of the microscope, and the results of chemical tests guide us, not only in our selection of the trees, but often teach us beforehand the causes and reasons of durability or decay.

The longevity of certain kinds of trees is marvellous. British oaks are estimated to attain an age of 2000 years. The Walnut

* Rhododendron arboreum attains a height of 30 feet, while Rh. Falconeri rises to 50 feet, with leaves half a yard long.

tree, the Sweet Chesnut, and Black Mulberry tree, live through many centuries, if cared for. Wellingtonias are found to be 1100 years old. Even the South European Elm, which since the time of the Romans has also made Britain its home, is known to stand 600 years. Dr. Hooker regards the oldest Cedars yet existing at Mount Lebanon as 2500 years old. Historic records are extant of Orange trees having attained an age of 700 years, yet aged trees continue in full bearing under favourable circumstances; a single tree is said to have yielded in a harvest 20,000 oranges. Individual Olive trees are also supposed to have existed ever since the Christian era. The European Cypress, the British Yew, the Ginkgo, and the Kauri, afford other remarkable instances of longevity.

The Date Palm gratefully bears its rich crop of fruit for 200 years. The Dragon tree of Orotava is another familiar example of extraordinary longevity. Here, in Victoria, the Native Beech and several Eucalypts are veritable patriarchs of the forests, and of a far more venerable age than is generally supposed.

So much for the lasting of some of our work, to encourage planting operations.

If Cook, who stepped with the pride of an explorer on these shores precisely a century ago, could view once more the scene of his discoveries, he would be charmed by the sight of noble cities, and the happy aspect of rural industry; but he would turn his eyes in dismay from the desolation and aridity which a merciless sacrifice of the native forests has already so sadly brought about—a sacrifice arising from an utter absence of all thoughts for the future. Ever since antiquity this work of forest destruction has gone on in every country, until sooner or later such reckless improvidence has been overtaken by a resentful Nemesis, in hindering the progress of national prosperity, and the comfort of whole communities.

After lengthened periods of toil there partially arose, but partially only, what an early guardianship might have readily retained for most countries. When I largely shared in the labours of establishing for Australian trees a reputation abroad, I certainly did also entertain a hope to awaken here likewise a universal interest in the dissemination of an almost endless number of trees from the colder and subtropic girdles of the whole globe. (Vide Phil. Inst., 1858, p. 93-109.) A few scattered trees are of no national moment. We want the massive upgrowth of the Pitch Pines, just as on the Pine barrens of the United States; we want whole forests of the

Deal Pines, both cis and transatlantic; we want over all our mountains the Silver Fir, already the charm of the ancients; we want the Australian Red Cedar, scarcely any longer existing in its native haunts; we want the Yarrah tree, forest-like as in West Australia; we want the various elastic Ash trees, which are so easily raised; we want, indeed, no end of other trees, because the greater part of Victoria is ill-wooded; because our climate is hot and dry; because extensive coal layers we have not yet found. What practical bearing can all the teaching in this hall, all the display in this museum, really exercise, if finally the artizan finds himself without an adequate and inexpensive material for his work? Annually the timber of 150,000 acres is cut away in the United States to supply the want for railway sleepers alone. The annual expenditure there in wood for railway buildings and cars is £7,600,000. In a single year the locomotives of the United States consume £11,200,000 of wood. The whole wood industries of the United States represent now an annual expenditure of one hundred millions sterling. There 400,000 artisans are engaged alone in woodwork. Here in Victoria, notwithstanding the activity of many sawmills, we imported only last year timber to the value of £270,572 for our own use. As these remarks may find publicity, I have appended further notes on timber trees, eminently desirable for massive introduction, but do not wish to exhaust by details the patience of this audience.

But it would be vain to expect that Europe and America will continue for ever to furnish for us their timber. The constantly increasing population and the augmented requirements of advancing industries will render no longer yonder woods accessible also to us before the century passes, because even in those northern countries the timber supply will then barely satisfy local wants.

An idea may be formed of forest value when we enter on some calculations of the supply of timber or other products available from one of our largest Eucalyptus trees. Suppose one of the colossal Eucalyptus amygdalina at the Black Spur was felled, and its total height ascertained to be 480 feet, its circumference towards the base of the stem 81 feet, its lower diameter to be 26 feet, and at the height of 300 feet its diameter 6 feet. Suppose *only half* the available wood was cut into planks of 12 inches width, we would get, in the terms of the timber trade, 426,720 superficial feet at one inch thickness, sufficient to cover 9¾ acres. The same bulk of wood

cut into railway sleepers, 6 feet x 6 inches x 8 inches, would yield in number 17,780. Not less than a length of 23 miles of three-rail fencing, including the necessary posts, could be constructed. It would require a ship of about 1000 tonnage to convey the timber and additional firewood of half the tree; and 666 drayloads at $1\frac{1}{2}$ tons would thus be formed to remove half the wood. The essential oil obtainable from the foliage of the whole tree may be estimated at 31 pounds; the charcoal, suppose there was no loss of wood, 17,950 bushels; the crude vinegar, 227,269 gallons; the wood tar, 31,150 gallons; the potash, 2 tons 11 cwt. But how many centuries elapsed before undisturbed nature could build up by the subtle processes of vitality these huge and wondrous structures!

Some feelings of veneration and reverence should also be evinced towards the native vegetation, where it displays its rarest and grandest forms. It is lamentable that in all Australia scarcely a single spot has been secured* for preserving some relics of its most ancient trees, to convey to posterity an idea of the original features of our primeval forests. Though it may appear foreign to my subject, I cannot withhold also on this occasion an imploring word, more particularly when I notice land-proprietors in East Australia to hold not even sacred a single native Banyan-tree, which required centuries for building its expansive dome and its hundreds of columnar pillars; nor to allow a single Cyrtosia Orchid to continue with its stem trailing to the length of thirty feet, and to remain with its thousands of large fragrant blossoms the pride of the forest. That very Cyrtosia gives a clue to the affinity and structure of other plants, not nearer to us than Java; and its destruction, with probably that of many others which the naturalist for ever is now prevented to dissect, or the artist to delineate, or the museum custodian to preserve, will be a loss to systematic natural history, also, for ever. Again, in a spirit of Vandalism, a Fan-palm, after a hundred years' growth, is no longer allowed to raise its slender stem and lofty crown in our own forests of Gipps Land, simply because curiosity is prompted to obtain a dishful of palm cabbage at the sacrifice of a century's growth.

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* On the River Hastings some magnificent dales have been lately protected by the Government of New South Wales for the sake of the incomparably beautiful and grand native vegetation, an example deserving extensive imitation. The forests of the Bunya Araucaria, occupying only a limited natural area, are also secured against intrusion by the Government.

Let it be remembered that the uncivilised inhabitants of many a tropical country know how to respect the original, and not always restorable gifts of a bountiful providence. They will invariably climb the Palm tree to obtain its nuts or to plait its leaves; so, also, a resident in our forests might obtain from a grove of our hardy palms, if still any are left in this land of Canaan, an annual income by harvesting the seeds as one of the most costly articles of horticultural export.

Speaking of palms, let me observe that the tall Wax-palm of New Granada (Ceroxlyon andicola) extends almost to the snow line. It is needless to add, that we might grow this magnificent product of Andine vegetation in many localities of the country of our own adoption. Each stem yields annually about 25 lb. of a waxy, resinous coating, which, when melted together with tallow, forms an exquisite composition for candles. Chamaerops Fortunei, a Chinese Fan-palm of considerable height, is here hardy, like in South Europe; so would be, probably, the Gingerbread Palm (Hyphaene Thebaica). Of the value of some palms we may form an appreciation when we reflect that Elais Guineensis, which at the end of this century should be productive in Queensland and North-west Australia, yields from the fleshy outer portion of its nut the commercially famed palm oil, prepared much in the manner of olive oil; the value of this African palm oil imported in 1861 into England was two millions sterling, the demand for it for soap manufacture, and railway engines and carriages, being enormous.* The Chilian Jubaea or Coquito Palm grows spontaneously as far south as the latitude of Swan Hill, and is rich in a melliginous sap.† A Date palm planted now would still be in full bearing 200 years hence.

When hopeful illusion steps beyond the stern realities of the day, it cannot suppress a desire that enlightened statesmanship will always wisely foresee the absolute requirements of future generations. The colonist who lives in enjoyment of his property near the ranges, and sees a flourishing family growing up around him, asks ominously what will be the aspect of these forests at the end of the century, if the present work of demolition continues to go on? He feels that though the forests donot solely bring us the rain, through forests only a comparatively arid country can have the full advantage

* The import of Palm Oil into Britain during 1868 was nearly a million cwt. (960,059 cwt.)

† Each tree yields 90 gallons of sap at a time, used for the preparation of palm-honey.

of its showers, as bitter experience has taught generation after generation since Julius Cæsar's time. The colonist reflects with apprehension, that while no year nor day when passed into eternity can be regained, no provision whatever is made for the coming population, in whose welfare, perhaps as the head of a family, and perhaps even bearing political responsibility, he is interested. He would gladly co-operate in the labours of a local forest board, just like members of road boards and shire councils enter cheerfully on the special duties allotted to their administration. His local experience would dictate the rules under which in each district the timber and other products of the forest could be most lucratively utilised without desolation for the future; and he would be best able to judge, and to seek advice how the yield of the forest could be advantageously maintained, and its riches methodically be increased. All this will weigh more heavily on his mind when he is cognisant that even in Middle Europe, in countries so well provided with coals, and of a much cooler clime than ours, the extent of the forests is kept scrupulously intact, and their regular yield remains secured from year to year and from century to century. He would rest satisfied if only the trifling revenue of the forests could be applied by him and his neighbours to an inexpensive restoration of the woods consumed. He would delight in seeing the leading foreign timber trees disseminated with our own Red Gum tree, Red Cedars, Yarrahs, or Blackwoods, not by hundreds but in time to come by millions, well aware that the next generations may either censure reproachfully the shortcomings of their ancestors, or may point gratefully to the results of an earnest and well-sustained foresight of future wants. As a first step, at least in each district a few square miles should be secured for subsequent forest nurseries in the best localities, commanding irrigation by gravitation, and ready access also, before it is too late, and all such spots are permanently alienated from the Crown.

Physical science must yet largely be called to our experimental aid before we can dispel the many crude notions in reference to the effect of forest vegetation on climate in all its details. It is thus a startling fact, as far as experiments under my guidance hitherto could elucidate the subject, that on a sunny day the leaves of our common Eucalypts and Casuarinas exhale a quantity of water several times, or even many times, larger than those of the ordinary or South European Elm, English Oak, or Black Poplar; while from the foliage of our native Silver Wattle only half, or even less than half, the

quantity of water is evaporated than from the Poplar or Oak. This degree of exhalation, so different in various trees, depends on the number, position, and size of their stomata, and stands in immediate correlation to the power of absorption of moisture. Besides, if the evaporation of Eucalyptus trees is so enormous during heat, and if the often horizontal roots of these trees thus render soil around them very dry, in consequence of the copious conveyance of moisture to the air, they simultaneously, by the rapidity of their evaporation in converting aqueous to gaseous liquid, or water into vapour, cause a lowering of the temperature most important in our climate during the months of extreme heat, while their capability of absorbing moisture during rain or from humid air must be commensurately great.

It is beyond the scope of this address to dwell further on facts like these; but I was anxious to demonstrate by a mere example how much we have yet to learn by patient research before we will have recognised in all its details the important part which forest vegetation plays in the great economy of nature. Concerning forest culture, I would very briefly allude to an instance showing how by the teachings of natural science and thoughtful circumspection the rewards of industrial pursuits may become surprisingly augmented. In the uplands of the Madras Presidency an ingenious method has been adopted in gathering the harvest of Cinchona bark, in recent very extensive plantations, by removing it in strips without destroying the cambium layer. Then by applying moss to the denuded part of the stem, not only is the removed portion of the bark renewed within a year to the thickness of three years' growth, but the protection of the tender bark against the influence of light and air allows nearly all the quinine and other alkaloids to remain retained in the cortical layer without decomposition, while in the ordinary three years' bark half or more of these principles is lost.

Facts like these lead us to appreciate the important bearings of the natural sciences on all branches of industry; but they warn us also to pause before we give our further consent to the unlimited and reckless demolition of our most accessible forest lands, on the maintenance of which so many of our industries depend.

Just as it required, even under undisturbed favourable influences, centuries before our forest riches were developed to their pristine grandeur, so it will need, in the ordinary laws of nature, at least an equal lengthened period before we can see towering up again the sylvan colosses, which eminently con-

tributed to the fame of the natural history of this land—if, indeed, the altered physical condition of the country will render the restoration of the trees on a grand scale possible at all.

Has science drawn in vain its isothermal girdles around the globe, or has the searching eye of the philosopher in vain penetrated geologic structure, or in vain the exploring phytographer circumscribed the forms? Well do we know what and where to choose; botanic science steps in to define the objects of our choice, which other branches of learning teach us to locate and rear.

The Tea would as thriftly luxuriate in our wooded valleys as in its native haunts at Assam, and yield a harvest far more prolific than away from the ranges. Indeed, we may well foresee that many forest slopes will be dotted in endless rows with the bushes of the Tea, precisely as our drier ridges are verdant with the vine. Erythroxylon Coco, the wondrous stimulating plant of Peru, should be raised in the mildest and most sheltered forest glens, where the stillness of the air excludes the possibility of cutting frosts. Hop, cultivated as a leading industry in Tasmania since a quarter of a century, will also take a prominent place on the brooks of our mountains. Peru Bark trees of various kinds should in spots so favoured be subjected to culture trials. How easily could any swampy depression, not otherwise readily of value, be rendered productive by allowing plants of the handsome New Zealand flax lily quietly to spread as a source for future wealth. How far the demand of material for industrial purposes may quickly exceed the supply may be strikingly exemplified by the fact, that hundreds of vessels are exclusively employed for bringing the Esparto grass (not superior to several of our most frequent sedges) from Spain to England, to augment the supply of rags for the endless increasing requirements of the paper mills. Conversion of manifold material, even sawdust, into paper is carried on to a vast extent; a multitude of samples placed here before you will help to explain how wide the scope for paper material may extend. But the factories want material, not only cheap, but readily convertible, and adapted to particular working.

In all these selections, a few glances through the microscope, and the result of a few chemical reactions taught in this hall, may at once advise the artisan in his choice.

Phytologic enquiry is further to teach us rationally the nature of maladies to which plants are subject, just as it discloses even the sources of many of the most terrific and

ravaging diseases of which the human frame is the victim. The microscope, that marvellous tool for discovery, has become also the guardian of many an industry. The processes of morbid growth, or the development and diffusion of the minute organism, between which descriptive botany knows how to discriminate, are thus traced out as the subtle and insidious causes which at times involve losses that count by hundreds of thousands in a single year, even in our yet small communities. But while the microscope discloses the form and development of the various minute organisms which cause, through the countless numbers of individuals, at times the temporary ruin of main branches of rural industry, it leaves us not helpless in our insight how to vanquish the invaders. In correctly estimating the limits of the specific forms, calling forth or concomitant with some of the saddest human maladies, phytography shares in the noble aim of alleviating human sufferings, or restoring health and prolonging vital existence.

But it comes most prominently within the scope of this industrial museum to delineate for the agricultural and forest section, in explanatory plates, the morbid processes under which crops and timber may succumb, and an industry be paralyzed or a country be verily brought to famine; it devolves on us, also, simultaneously to explain the effect of remedial agents, such as sound reasoning from inductive science suggests or confirms. To array samples of all field products which our genial clime allows us to raise is doubtless the object of an instructive institution, more particularly in a young country, to which immigration streams mainly from a colder zone; but this display of increased capabilities, and of more varied products of a mostly winterless land, may entice the inexperienced to new operations without guarding him against failures. I should even like to see tables of calculations in this museum, from which could be learnt the yield and value of any crop within a defined acreage and from a soil chemically examined; but from this I would regard inseparable a close calculation of the costs under which each particular crop can only be raised. Unfortunately, surprising data are often furnished concerning the productiveness of new plants of culture; but it is as frequently forgotten, that the large yield is as a rule dependent on an expenditure commensurately large.

Among the most powerful means for fostering phytologic knowledge for local instructive purposes, that of forming collections of the plants themselves remains one of the foremost. No school of any great pretension should be without a local

collection of museum plants, nor should any mechanics' institute be without such. It serves as a means of reference most faithfully; it need not be a source of expenditure; it might be gathered as an object of recreation; it may add even to the world's knowledge. Through the transmission of numbered duplicate sets of plants to my office the accurate naming may be secured.* From such a normal collection in each district the inhabitant may learn to discriminate at once with exactness between the different timber trees, the grasses, the plants worthy of ornamental culture, or any others possessing industrial or cultural interest. The sawyer, as well as the trader in timber, may learn how many of the 140 Australian Eucalypts occur within his reach—how phytography designates each of them by a specific appellation acknowledged all over the globe. Phytologic inquiry, aided by collateral sciences, will disclose to him beforehand the rules for obtaining the wood at the best seasons, for selecting it for special purposes, for securing the best preservation. Phytochemistry will explain to him what average percentage of potash, oils, tar, vinegar, alcohol, tannic acid, &c., may be obtained under ordinary circumstances from each. He will understand, for instance, that the so-called Red Gum tree of Victoria, the one so famed for the durability of its wood and for the peculiar medicinal astringency of its gum resin, is widely different from the tree of that vernacular named in Western Australia; that it is wanting in Tasmania, yet that it has an extensive geographic range over the interior of our continent; and that thus the experiences gained on the products of this particular species of tree by himself or others are widely applicable elsewhere. Through collections of these kinds the thoughtful colonist may have his attention directed to vegetable objects of great value in his own locality, of the existence of which he might otherwise not readily become aware. New trades may spring up, new exports may be initiated, new local factories be established. Phytographic works on Australian plants, now extant in many volumes, can readily be attached and rendered explanatory of such collections. A prize held out by the patrons of any school might stimulate the

* Parcels of plants pressed and dried, and afterwards closely packed, can be inexpensively forwarded by post, and by the excellence of the Australian postal arrangements can be sent from distant stations of the interior, from whence botanical specimens of any kind, for ascertaining the nature and range of the species, are most acceptable: while full information on such material will at once be rendered.

juvenile gatherer of plants to increased exertions; his youthful mind will be trained to observation and reflection, and the faculties of a loftier understanding will be raised.

To the adult also, and particularly often to the invalid, new sources of enjoyment may thus be disclosed. What formerly was passed by unregarded, will have a meaning; every blade over which he stepped thoughtlessly before will have a new interest; and even what he might have admired will gain additional charm; but while penetrating wonders he never dreamt of before, he ought piously to ask who called them forth?

"Bright flowers shall bloom wherever we roam,
A voice divine shall talk in each stream;
The stars shall look like worlds of love,
And this earth shall be one beautiful dream."
—*Thos. Moore's Irish Melodies.*

What one single plant may do for the human race is perhaps best exemplified by the Cotton plant. The Southern States of North America sent to England in 1860 nearly half a million tons of cotton (453,522 tons), by which means, in Britain alone, employment was given to about a million of people engaged in industries of this fabric, producing cotton goods to the value of £121,364,458. From Rice, which like the Cotton will mature its crop in some of the warmer parts of Victoria,* sustenance is obtained for a greater number of human beings than from any other plant. In the greater part of the Australian continent, wherever water supply could be commanded, the Rice would luxuriate. I found it wild in Arnheim's Land in 1855. Of Sugar Cane the hardier varieties may within Victoria succeed in East Gipps Land, and other warmer spots. Great Britain imported in 1863 not less than 586,600 tons.† Even our young colony imported last year to the value of nearly a million sterling (£948,329). Think of the commerce in other vegetable products, such as require in different places our local fostering care in order to add still more to our resources. Of various Tobaccoes we imported into Victoria in 1869 (deducting exports) to the value of £83,788; of Wine, £84,687; of Cereals, £781,250; of Paper, £123,158. I will not enter on any remarks about Sugar-beet, on which

* Particularly if the hardy mountain Rice of China and Japan is chosen, which requires no irrigation. The ordinary rice has been grown as far north as Lombardy.

† The total import of Sugar into Britain was—

During 1868	... ...	626,301 tons
„ 1869	... ...	605,129 „

one of our fellow-colonists has lately compiled an excellent treatise. Of Tea, in 1865 Britain required for home consumption eighty-five millions of lbs.* What a prospect for tea growth in Victoria, where this bush cares neither for the scorching heat of the summer nor for the night-frosts of our lower regions; whereas in the forest glens of our country, Tasmania, and elsewhere, the Tea-bush would yield most prolific harvests. Test plantations for manifold new cultures were recommended by me years ago in one of my official reports to the Legislature; one plantation for the desert, one for subalpine regions, one for the deep valleys of the woodlands. The two latter might be in close vicinity at the Black Spur, and thus within the reach of ready traffic. The outlay in each case would be modest indeed. What an endless number of new industrial plants might thus be brought together within a few hours' drive of the city, under all the advantages of rich soil, shelter, and irrigation! What an attractive collection for the intelligent and studious might thus be permanently formed.

I will not weary this audience by giving a long array of names of any plants resisting alpine winters, such as in our snow-clad higher mountains they would have to endure. We know that the Apple will live where even the hardy Pear will succumb; both will still thrive on our alpine plateaus. The Larch, struggling in vain with the dry heat of our open lowlands, would be a tree of comparatively rapid growth near alpine heights. The Birch, in Greenland the only tree, in Italy ascending to 6000 feet, in Russia the most universal, and there yielding for famed tanning processes its valued bark, is living—to quote the forcible remarks of an elegant writer—"is living on the bleak mountain sides from which the sturdy Oak shrinks with dismay." Add to it, if you like, the Paper Birch, and a host of arctic, Andine, and other alpine trees and bushes. Disseminate the Strawberries of the countries of our childhood, naturalise the Blackberry of northern forest moors. The American Cranberry-bush (Vaccinium macrocarpum), with its large fruits, is said to have yielded on boggy meadows, such as occupy a large terrain of

* The total import of Tea into Britain was—

During	1865	121,156,712 lbs.
„	1866	139,610,044 „
„	1867	128,028,726 „
„	1868	154,845,863 „
„	1869	139,223,298 „

the Australian Alps, fully one hundred bushels on one acre in a year, worth so many dollars. If once established, such plant would gradually spread on its own account for the benefit of future highland inhabitants. The Sugar Maple would seek these cold heights, to be tapped when the winter snow melts. For half a century it will yield its saccharine sap, equal to several pounds of sugar annually.

Let us translocate ourselves now for a moment to our desert tracts, changed as they will likely be many years hence, when the waters of the Murray River in their unceasing flow from snowy sources will be thrown over the back plains, and no longer run entirely into the ocean, unutilised for husbandry. The lagoons may then be lined, and the fertile depressions be studded, with the Date Palm; Fig trees, like in Egypt planted by the hundreds of thousands to increase and retain the rain, will then also have ameliorated here the clime; or the White Mulberry Tree will be extensively extant then instead of the Mallee scrub; not to speak of the Vine in endless variety, nor to allude to a copious culture of Cotton in those regions. To Fig trees and Mulberry trees I refer more particularly, because it must be always in the first instance the object to raise in masses those utilitarian plants which can be multiplied with the utmost ease and without special skill, locally, and which, moreover, as in this case, would resist the dry heat of our desert clime. When recommending such a culture for industrial pursuits, it is not the aim to plant by the thousand but by the million. Remember, also, that a variety of the Morus Alba occurs in Affghanistan, with a delicious fruit; and that the importation of Figs into Britain alone, from countries in climate alike to large tracts of Victoria, has been of late years about one thousand tons annually. What the Fig-tree has effected for rainless tracts of Egypt is now on historic record.

I have spoken of horticultural industries as not altogether foreign to this institution—indeed, as representing a rising branch of commerce. Were I to enter on details of this subject the pages of this address might swell to a volume. But this I would mention, that in our young country the manifold facilities for rearing exotic plants in specially selected and adapted localities could only as yet receive imperfect consideration. We have, however, ample opportunities of selecting genial spots for the growth of such singular curiosities as the Flytrap plant (Dionæa Muscipula) and the Pitcher plants (Sarracenias) of the bogs and swamps of the

pine barrens and savannahs of Carolina, if we proceed to moory portions of our springy forest land. There is no telling, too, whether the Pitcher plants of Khasya and China (species of Nepenthes) could not readily be grown and multiplied in similar localities, and the hardier of grand Epiphytes among the orchids, such as the subalpine Oncidium Warczewickyi) of Central America, which might readily be reared in our glens by horticultural enterprise, together with all the hardier Palms which modern taste has so well adopted for the ready decoration of dwelling rooms.

Such plants as the Beaucarnea recurvata of Mexico, with its 5000 flowers in a single panicle, and the hardier Vellozias from the bare mountain regions of Brazil, would endure our open air; while the innumerable South African heaths, Stapeliæ, the Mesembryanthema, Pelargonia, lily-like plants, and many others, once the pride of European conservatories, can with increased sea traffic now gradually be introduced as beautiful objects of trade into this country, where they need no glass protection. It leads too far to speak of the still more readily accessible numerous showy plants of South-west Australia, but among which, as a mere instance, the gorgeous Anigozanthi, the lovely Stylidia, the gay Banksiæ, and the fragrant Boronias may be mentioned.

Before leaving this topic, I may remind you that many esculent plants of foreign countries are deserving yet of test culture, and, perhaps, general adoption in this country. The Dolichos sesquipedalis of South America is a bean, cultivated in France on account of its tender pod. The Arracha esculenta, an umbellate from the cooler mountains of Central America, yields there, for universal use, its edible root. The climbing Chocho of West India (Sechium edule) proved hardy in Madeira, and furnishes a root and fruit both palatable and wholesome. Vigna subterranea is the Earth Nut of Natal. The Tara of Tahiti (Calocasia macrorrhiza), though perfectly enduring our lowland clime, is as yet, with allied species, but little cultivated—neither the Soja of Japan (Glycine Soja), nor the Caper of the Mediterranean. The Seakales (Crambe Maritima and C. Tatarica) might be naturalised on our sandy shores.

Regarding fibres, much yet requires to be effected by capitalists and cultivators to turn such plants as the Grasscloth shrub, which I distributed for upwards of a dozen years, to commercial importance for factories. A kind of Jute (Corchorus olitorius) succeeds as far north as the Mediterranean, and grows wild

with the Sunn Hemp (Crotalaria juncea) in tropical Australia; the latter plant comes naturally almost to the boundaries of our colony. A Melbourne rope factory offers £36 for the ton of New Zealand Flax, and can consume six tons per week. Hemp, used since antiquity, produces along with its fibre the Hypnotic Churras. England imported in 1858 Hemp to the value of more than one million pounds.* This may suffice to indicate new resources in this direction. For Sumach our country offers in many places the precise conditions for its successful growth, as I confirmed by actual tests. Tannic substances, of which the indigenous supply is abundant and manifold, would assume still greater commercial importance by simple processes of reducing them to a concentrated form. How on any forest river might not the Filbert tree be naturalised; on precipitous places, among rocks, it would form a useful jungle, furnishing, besides its nuts, the material for fishing-rods, hoops, charcoal crayons, and other purposes. From a single forest at Barcelona 60,000 bushels are obtained in a year. (For these and many other data brought before you in this lecture you may refer further, most conveniently, to a posthumous work of the great Professor Lindley, *Treasury of Botany*, edited by Mr. Th. Moore, with the aid of able contributors.) Even the Loquat would attain in our forest glens the size of a fair, or even large tree.

Osiers and other willows used for basket work, for charcoal, or for the preparation of salicine, might line any river banks, quite as much for the sake of shade and consolidation of the soil as for their direct utilitarian properties. In the forest ranges any dense line of Willows and Poplars will help to check the spread of the dreadful conflagrations in which so much of the best timber is lost, and through which the temperature of the country is for days heightened to an intolerable degree far beyond the scenes of devastation, while injuries are inflicted far and wide to the labours in the garden or the field. In the most arid deserts the medicinal Aloes might readily be established, to yield by a simple process the drug of commerce. Gourds of half a hundredweight have been obtained in Victoria, and show what the plants of the Melon tribe might do here, like in South Africa, for eligible spots in the desert land. Among the trees for those arid tracts, the glorious Grevillea robusta, with its innumerable trusses of fiery

* The import of Hemp and Jute into Britain during 1868 was 3,281,268 cwt.; during 1869, 3,551,838 cwt. The undressed Hemp imported in 1868 was valued at £2,022,419.

red and its splendid wood for staves, is only one of the very many desirable; just as in the oases the Carob tree will live without water uninjured, because its deeply-penetrating roots render it fit to resist any drought. But it may be said that much that I instance is well known and well recorded—so, doubtless, it is, in the abstract—but variety requires to be distinguished from variety, species from species, and their geography, internal structure, and components need carefully be set forth, before any industry relating to plants can be raised on sound ground in proper localities, and be brought to its best fruitfulness.

Even a pond, a streamlet—how, with intelligent foresight, may it be utilised and rendered lucrative to industry! The Water Nuts,* naturally distributed through large tracts of Europe and Asia, afford at Cashmere alone for five months in the year a nutritious and palatable article of food to 30,000 people. Can the Menyanthes not be made a native here—one of the loveliest of water plants, one of the best of tonics? The true Bamboo, which I first proved hardy here, used for no end of purposes by the ingenious Chinese—can we not plant it here at each dwelling, at each stream, a grateful yielder to industrial wants, not requiring itself any care, an object destined to embellish whole landscapes? An Arundinaria Bamboo from Nepal (A. falcata) proved very tall and quite hardy even in Britain; and yet taller is the Mississippi Arundinaria (A. macrosperma)—indeed, rivalling in height the gigantic Chinese or Indian Bamboo.

Imagine how there might arise on the bold rocky declivities of the Grampians the colossal columns of the Cereus giganteus of the extra-tropic Colorado regions—huge candelabras of vegetable structure, which would pierce the roof of our museum hall if planted on the floor, and would be as expansive in width as the pedestal of the monument consecrated to our unfortunate explorers. Picture to yourselves an Echinocactus Visnago of New Mexico, lodged in the wide chasm of our Pyrenees, one of these monsters weighing a ton, and expanding into a length of nine feet, with a diameter of three feet. Think of such plants mingled with the Canarian Dragon tree, one of which is supposed to have lived from our Redeemer's time to this age, because four centuries effected on these Giant Lilies but little change. Welwitchia here, like in rainless Damaraland, might grow in our desert sands as one of the

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* Several species of Trapa.

most wonderful of plants, its only pair of leaves being cotyledonous and lasting well-nigh through a century. Or associate in your ideas with these one of the medicinal Tree Aloes of Namaqua, or one of the Poison Euphorbias, never requiring pluvial showers (Euphorbia grandidens), some as high as a good-sized two-storeyed dwelling-house; transfer to them also Cereus senilis, thirty feet high, which with all its attempts to look venerable only succeeds to be grotesque; add to these extraordinary forms such Lily trees as the Fourcroya longæva, with a stem of forty feet and an inflorescence of thirty feet, whereas Agave Americana, Agave Mexicana and allied species, while they quietly pass through the comparatively short space of time allotted to their existence, weave in the beautiful internal economy of their huge leaves the threads, which are to yield the tenacious Pita cords, so much in quest for the rope bridges of Central America.

Some of the Echinocacti extend as far south as Buenos Ayres and Mendoza, and would introduce into many arid tracts of Victoria, together with the almost numberless succulents of South Africa, a great ornamental attraction, which horticultural enterprise might turn to lucrative account; just like our native showy plants will yet become objects of far higher commercial importance, than hitherto has been attached to them. The columns of Cereus Peruvianus rise sometimes to half a hundred feet; some Cacteæ are in reality the vegetable fountains of the desert. Such plants as Echinocactus platyceras, with its 50,000 thorns and setæ, should be cultivated in our open grounds for horticultural trade, whereas the Cochineal Cacti (Opuntia Tuna, O. coccinellifera and a few other species), might well be still further distributed here, in order that food may be available for the Cochineal insects when other circumstances in Australia will become favourable for the local production of this costly dye.

These are a few of the many instances which might be adduced to demonstrate how the landscape pictures of Victoria might be embellished in another century, and new means of gain be obtained from additional manifold resources.

But while your thoughts are carried to other zones and distant lands, let us not lose sight of the reason for which we assembled, namely, to deal with utilitarian objects and the application of science thereon. All organic structures, however, whether giants or pygmies, whether showy or inconspicuous, have their allotted functions to fulfil in nature, are destined to contribute to our wants, are endowed with their

special properties, are heralding the greatness of the Creator. But here in this hall I would like to see displayed by pictorial art the most majestic forms in nature, were it only to delineate for the studious the physiognomy of foreign lands, irrespective of any known industrial value of the objects thus sketched. The painter's art in choosing from nature does impress us most lastingly with the value and grandeur of its treasures. Each plant, as it were, has a history of discovery of its own; who would not like to trace it? And this again brings us face to face with those who carried before us the torch of scientific inquiry into the dark recesses of mystery, and shed a flood of light on perhaps long-concealed magnificence and beauty. The youth, aroused to the sublime feeling of wishing at least to follow great men in independent researches, may be animated, if in a hall like this each division were ornamented with the portraits of the foremost of those discoverers, who through ages advanced knowledge to the standard of the present day.

> "Deeds of great men all remind us
> We can make our lives sublime,
> And departing leave behind us
> Footprints on the sands of time.
>
> "Though oft depressed and lonely,
> Our fears are laid aside,
> If we remember only
> Such also lived and died.
>
> "Learn from the grand old masters,
> Or from the bard sublime,
> Whose distant footsteps echo
> Through the corridor of time."
>
> LONGFELLOW.

Discovery proceeds step by step. Commenced by original thinkers, enlarged by sedulous experimenters, fostered by the thoughtful portion of the community, and by any administration of high views, it is utilised by well-directed enterprise, and marches onward steadily in its progress. Guttenberg and his collaborators gave us the printing art, which has done more to enlighten the world than all other mechanisms taken together; and though four centuries have altered much in the speed and cost of producing prints, they have not materially changed the forms of this glorious art, as the beautifully-decorated pages of the earliest printed bibles testify. Thus we have reason to be yet daily grateful for this invaluable gain from the genius of days long passed.

Thoughtless criticism is but too often impatient of success, and demands results premature and unreasonable. Incompetent and perversive censure may even carry the sway of public opinion—misleading, and misled; and still worse organised tactics may apply themselves, for sinister purposes of their own, to disturb the quiet work of the discoverer, mar the results of his labours, or paralyse the vitality of research, not understanding, or not wishing to understand, its direction or its object.

And yet, should we have no faith in science, whether it reveals to us the minutest organisms in a perfection unalterable,* or the grandest doctrines of truth, sure ever to bear on human happiness and the peace of our soul; should we have no faith in science, whether it unravels the metallic treasures of the depth and the coals of the forests of bygone ages, or by eternal laws permits us to trace the orbits of endless celestial worlds through space; no faith, if it allows us through spectroscopic marvels to count unerringly the billions of oscillations of each ray of dispersed light within a second; or if it discloses the chemism of distant worlds, and therewith an applicability of research, both tellurial and sidereal, ever endless and inexhaustible. Science, as the exponent of Godlike laws, draws us in deepest veneration to the power divine. That is true science!

"As into tints of sevenfold ray
Breaks soft the silvery shimmering white;
As fade the sevenfold tints away,
And all the rainbow melts in light;
So from the Iris sportive call
Each magic tint the eye to chain,
And now let truth unite them all,
And light its single stream regain."
—*Bulwer Lytton, from Schiller.*

If a series of experiments with colouring principles from coal tar and bituminous substances led to the invention of

* As an instance of the marvellous complexity, and yet exquisite perfection of the minutest creatures, the organ of vision in insects may be adduced. Most careful observers have ascertained that the eyes of very many insects are compound, contain numerous eyelets; each of these provided with a distinct cornea, lens, iris, pupil, and a whole nervous apparatus. In our despised ordinary house fly may be counted about 4000 of these most subtle instruments of vision; in some dragon flies about 12,000. Reliable microscopists have counted even 17,355 in a kind of butterfly, while in the beetle genus mordella these most delicate eyelets have been found to rise to the almost incredible number of 25,088.—*(From Th. Rym. Jones.)*

the brilliant anilin colours, and brought about an almost total change in many dye processes, how many new wonders may not be disclosed to technology by the rapid strides of organic chemistry? As is well-known, three or four chemic elements are only engaged in forming numberless organic compounds, by a slight increase or decrease or rearrangement of the atomic molecules, constructing, for instance, from these three or four elements, ever present and ever attainable, the deadly Hydrocyanic Acid, the terrible Atropin, or the dreadful Aconitin at one time; or at another time, harmless Ammonia combinations universally used for culinary and other purposes of daily life. Our wood-tars, we may remember, are left as yet almost unexamined as regards their chemic constituents. Few of our timbers have been chemically analysed; few other of our vegetable products are as yet accurately tested. What an endless expanse for exploration does organic chemistry thus offer us! We are called on, among a thousand things, to trace out similar mutual relation and counteraction of such extremely powerful plants as the Belladonna and Calabar Bean. Here medicine, chemistry, and phytology, go hand in hand. How, again, is any analysis of the chemic constituents of any plant, for cultural purposes or otherwise, to be applied, unless we command a language of phytographic expressions, which will name with never-failing precision the object before us, and give to its elucidation value and stability?

We may speak chemically of potash plants, lime plants, and so forth; we may wish to define thereby the direction of certain industrial pursuits, and we may safely thereby foretell what plants can be raised profitably on any particular soil or with the use of any particular manure; but how is this knowledge to be fixed without exact phytologic information, or how is the knowledge to be applied, if we are to trust to vernacular names, perplexing even within the area of a small colony, and useless, as a rule, beyond it? Colonial Box trees by dozens, yet all distinct, and utterly unlike Turkey Box; colonial Myrtle, without the remotest resemblance to the poet's myrtle; colonial Oaks, analogous to those Indian trees, which as Casuarinæ were distinguished so graphically by Rumpf already 200 years ago, but without a trace of similarity to any real oak—afford instances of our confused and ludicrous vernacular appellations. A total change is demanded, resting on the rational observations and deductions which science already has gained for us. Assuredly, with any claims to ordinary intelligence, we ought to banish such designations, not only

from museum collections, but also from the dictionary of the artisan.

One of the genera of Mushrooms, certainly the largest of them (Agaricus), contains alone about a thousand species well distinguished from each other, a good many even occurring in this country. For the practical purposes of common life it becomes an object to distinguish the many wholesome from the multitude of deleterious kinds, or the circumstances under which the harmless sorts may become hurtful. In France the cultivation of mushrooms in underground caverns has become a branch of industry not altogether unimportant. How, in other instances, is many a culinary vegetable to be distinguished from the poison herb without the microscope of the phytographer being applied to dissections, or without the language of science recording the characters? How many a life, lost through a child's playfulness, or through the unacquaintance of the adult even with the most ordinary objects of knowledge among plants, might have been saved, even in these times of higher education, if phytologic knowledge was more universal? The species of fungi which can be converted into pleasant, nutritious food are far more numerous than popularly supposed, but for extending industries in this direction botanic science must assume the guardianship. In a technologic hall like this, I should like to see instructive portraits also of all the edible and noxious plants, likely to come within the colonist's reach.

Among about one thousand kinds of Fig-trees which (so Mons. Alphonse de Candolle tells me), through Mons. Bureau's present writings for the Prodromus, are ascertained to exist, only one yields the fig of our table, only one forms the famed Sycamore fig, planted along so many roads of the Orient; only one constitutes our own Ficus macrophylla, destined, in its insurpassed magnificence, to overshade here our pathways. How are these thousands of species of Ficus, all distinct in appearance, in character, and in uses—how are they to be recognised, unless a diagnosis of each becomes carefully elaborated and recorded, headed by a specific name?

Without descriptive botany, all safe discrimination becomes futile. To bear our share in building up an universal system of specific delimitation of all plants is a task well worthy of the patronage of an intelligent and high-minded people. The physician is thereby guided to draw safe comparisons in reference to the action of herbs and roots which he wishes to prescribe, as available from native resources. Thus it was

through Victorian researches, that not only the close affinity of Goodeniaceæ to the order of Gentianeæ was brought to light, but simultaneously a host of herbs and shrubs of the former order gained for therapeutic uses. When once it was ascertained that the so-called Myrtletree of our forest moors was a true Beech, the artisan then also found offered to him a timber of great similarity to that of the beech forests of his British home.

Of the grass genus Panicum, we know the world possesses, according to a recent botanic disquisition, about 850 species, all more or less nutritive. But one only of these is the famous Coapin of Angola (Panicum spectabile), one the Warree (Panicum miliaceum), one the Bhadlee (Panicum pilosum), one the Derran (P. frumentaceum). We might dispense perhaps, as far as these few are concerned, with their scientific appellations, though not even the mere task of naming has become therewith easier, and no information whatsoever of their characteristics has been gained. But if we wish to refer to any of the many hundred other species of Panicum, in what way are we to express ourselves if even their vernacular names could be collected from at least a dozen of languages, and impressed on any one's memory? They are, as may readily be imagined, very different indeed in their special nutritiveness, degree of endurance, and length of life. Of 140 species of Bromus, only one is the Prairie Grass, which attained already a great celebrity as a pasture grass naturalised in this country; and it is only one other Bromus, among the many nutritious kinds, which carries the palm as the most fattening fodder grass for cold, marshy pastures, and gradually, through depasturing, surpresses completely all other grasses and weeds; so it is proved on the marshlands of Oldenburg. This Bromus (B. secalinus), as far as I am cognisant, is nowhere as yet economically cultivated in Victoria.

Nothing would be easier than to commence disseminating a number of the best grasses in addition to those already here; for instance, the Canadian Rice Grass (Hydropyrum esculentum) for our swamp lands. Their nutritive value must be tested by analysis and other experiments, just like that of the Saltbushes of the Murray Flats. Hence ample scope for the exertions of science also in this direction.

In Cotta's celebrated publishing establishment at Stuttgart, a most useful work is issued by my friend, Prof. Noerdlinger, on the structure of timber of various kinds, illustrated by microscopic sections of the wood itself; for the latter fascicles

I furnished some material from this colony. The work should be accessible in this museum to all interested in wood work.

How much we have yet to learn of the value of our forest products is instanced when we now know from Spanish physicians to combat ague with Eucalyptus leaves, or when Count Maillard de Marafy, from experiments instituted this year in Egypt, announced to us that Eucalyptus leaves can be used as a substitute for sumach. (Egypte Agricole, 1870.)

Already in the earlier part of this lecture I spoke of the Peru Bark Plants; but the Cinchonas are not all of the same kind. Some endure a lower degree of temperature than others, some are richer in quinine, others richer in cinchonine, others in quinoidine; and this again is much subject to fluctuations under different effects of climate and soil. Great errors may be committed, and have been committed, by adopting from among a number of species the least valuable, or one under ordinary circumstances almost devoid of alkaloid, though a representative of the genus cinchona, and not unlike the lucrative species. When calculations in India prognosticate the almost incredible annual return of 130 per cent. after four years on the original outlay for Cinchona plantation, it is supposed that the conditions for this new industrial culture are to the utmost favourable. That one of the best species did not thrive there at all in proportion to expectations, is owing, in my opinion, to geologic conditions. The cinchonas before you, reared in soil from our Fern tree gullies, I intended to have tested for the percentage of their alkaloids prior to this evening; but the timely performance of this investigation was frustrated. I think, that I have proved the hardiness or adaptability of these important plants for the warm Palm valleys of East Gipps Land, as many indigenous plants from that genial spot are quite as much, if not more, susceptible of the night frosts of our city than the Cinchonæ, if harsh cutting winds are kept from the latter. But as yet I am unacquainted with the likely results of remunerative Cinchona cultivation within the boundaries of this colony, as far as such depends on the constituents of the soil. That inquiries of this kind are not mere chimeras, may be conceded after an explanation of this kind for the benefit of future technology. Geology, one of the brightest satellites which rotate around the sun of universal science, continues to send its lustre into the darkness which yet involves so many of the great operations in tellurian nature. Further insight into the relation of this discipline of science to vege-

table physiology is certain to shed abundance of light also on many branches of applied industry. The causes why the Ironbark trees of our auriferous quartz ridges differ so materially from the conspecific tree of alluvial flats can only be explained geologically. So it is with the narrow-leaved Eucalyptus amygdalina on open stony declivities as compared with the broad-leaved Eucalyptus fissilis, which in such gigantic dimensions towers up from our deep forest valleys. But all this has an important bearing on technological exertions in manifold directions. The timber chosen by the artisan from a wrong locality may impair the soundness of a whole building; or a factory may prove not lucrative simply because it is placed on a wrong spot for the best raw material.

A thousand of other industrial purposes might yet be served by a close knowledge of plants. So the designer might choose patterns far more beautiful from the simple and ever perfect beauty of nature than he gains from distorted forms copied into much of our tapestry; thus a room, now-a-days, as a rule, decorated with unmeaning, and often, as far as imitation of nature is concerned, impossible figures, might become, geographically or phytographically, quite instructive. If here the founders of territorial estates—some, perhaps, as large as the palatinates of the Middle Ages—should wish to perpetuate the custom of choosing a symbol for family arms, they, as the Highland clans adopted special plants of their native mountains for a distinguishing badge, might select as the ancestral emblem the flowers of our soil, destined, perhaps, to be traced, not without pride, by many a lineage through a hundred generations.

Precise knowledge of even the oceanic vegetation, in its almost infinite display of forms, offers not merely the most delicate objects for design, but brings before us its respective value for manure, or the importance of various herbage on which fishes will feed; while such marine weeds may as well be transferred from ocean to ocean as ova of trout have been brought from the far north to these distant southern latitudes. Who could foresee when first Iodine was accidentally discovered in seaweeds, through soda factories, or Bromine subsequently appeared as a mere substance of curiosity, what powerful therapeutic agents thereby were gained for medicine, what unique results they would render for chemical processes, of what incalculable advantages they would prove in physiological researches or microscopic tests; and how, without them, photographic art could not have depictured with unerring fidelity millions of objects, whether of landscapes or of the

starry sky, whether of the beings dear to us or the relics of antiquity, whether enlarging the scope of lithography or recording the languages which the flashing of telegraphic electricity sends to a dwelling or to an empire? Even the vegetable fossils, deep buried in the earth or in the cleavage of rocks, when viewed by the light of phytology become so many letters on the pages of nature's revelation, from which we are to learn the age of strata, or may trace the sources of metallic wealth, or by which we may be guided to huge remnants of forests of bygone ages, stored up for the utilisation of this epoch, or may comprehend, as far as mortal understanding serves us, successive changes in tellurian creation.

When Ray, and subsequently Jussieu, framed the first groundwork for the ordinal demarcation of plants; when Tournefort by defining generic limits brought further clearness into the chaos of dawning systematic knowledge, and when Linné gave so happily to each plant its second or specific name, but little was it indeed foreseen what a vast influence these principles of sound methodic arrangement would exercise, not only on the easy recognition of the varied forms of vegetable life, but also on the philosophic elucidation of their properties and uses, and this for all times to come. Many even at the present day, and among them at times those on whom the destinies of whole states and populations may depend, can recognise in phytographic and other scientific labours but little else than a mere playwork; yet without such labours every solid basis for applying the knowledge of plants to uses of any kind would be wanting. We would stray, indeed, unguided in a labyrinth between crude masses or inordinate fragments, instead of dwelling in a grand and lasting structure of knowledge, unless science, also in this direction, had raised its imperishable temples. But how much patient and toilsome research had to be spent thus to bring together in a systematic arrangement all the products of this wide globe; how many dangers of exploring travellers had to be braved to amplify the material for this knowledge, and how many have to pass away even now-a-days, persecuted and worried like Galileo at his time, no one yet has told, nor will tell. Well may we feel with the great German poet, as expressed in Bulwer Lytton's beautiful wording:—

" I will reward thee in a holier land,
Do give to me thy youth!
All I can grant you lies in this command—
I heard, and trusting in a holier land,
Gave my young joys to truth."

But is there nothing higher than the search of earthly riches, and is to this all knowledge of the earth's beautiful vegetation also to be rendered subservient? Is there nothing loftier than to break the flowers for our gaieties or to strew them along a mirthful path? There is! They raised the noblest feelings of the poet at all ages, they spoke the purest words of attachment, they ever were the silent harbingers of love. They smilingly inspired hope anew in unmeasured sadness, and on the deathbed or at the grave they appear to link together, as symbols of ever-returning springs, the mortal world with immortality; they ever teach us some of the sublimest revelations of our eternal God.

The laurel crown of the hero was a people's highest reward of chivalrous and glorious deeds.

The myrtle, or orange wreath for bridal curls, remains the proudest gift to youthful hope.

The little blooming weed, content in a parched and dreary desert, revived the strength of many a sinking wanderer (Mungo Park); the ever unalterable beauty and harmony of floral structures preaches the truths of eternal laws in the universe—a faith that gave expression to Schiller's memorable words, as repeated by that leading British statesman, "It's not all chance the world obeys." (Gladstone.) The innocent loveliness of nature's flowers has often aroused anew the shaken spirit of the philosopher, and to these and other gifts of nature the American bard alludes, when he speaks of the great zoologist, Agassiz, of whose friendship I may well be proud.

"And whenever the way seemed so long,
Or his heart began him to fail,
She would sing a still more wondrous song,
Or tell a more marvellous tale."

And when it seems that all hopes of the weeping mother are extinguished, or even the teachings of religion may well-nigh forsake her, then the deep meaning of some of our noblest poems inspired by nature is understood, and faith in eternity once more embraced.

"And the mother gave in tear and pain
The flowers she most did love,
She knew she would find them all again
In the fields of light above."

"And with childlike credulous affection
We behold their tender bud expand,
Emblems of our own great resurrection,
Emblems of the bright and better land."

A COURSE OF SIX LECTURES

ON

APPLIED CHEMISTRY.

DELIVERED BY GEORGE FOORD.

LECTURE I.

CHEMISTRY APPLIED TO MANUFACTURES.

15*th* *SEPTEMBER,* 1870.

The subject of this evening's lecture—"Chemistry applied to Manufactures"—is a comprehensive one, so much so as to demand for its treatment a strict economy of the time at our disposal.

In attending to the business before us, something must be said regarding the science of chemistry itself and its development, but we shall save time by avoiding the discussion of what are generally allowed to be obvious facts; we may therefore safely take for granted that chemical pursuits are useful, that chemical knowledge is profitable to the individual, and that chemical teaching, encouraged as a branch of national education, has broad advantages. With your concurrence we shall bestow our time upon topics more immediately concerning our own business, as a new community, possessed of superabundance of raw material which we are anxious to apply to useful purposes.

Let it be our business to ascertain something concerning chemical facts, how they are arrived at, and how chemistry is subsidized for the support of the useful arts. Let us select examples showing how manufactures depending on chemical principles have originated, and how the progress of applied chemistry depends on the cultivation of pure chemical science; and let us ascertain how the Vic-

torian manufacturer should proceed so as to be "up to the mark" in the method of his manufacture, always founding our precept upon reliable example. According to this plan, I propose in the first place to occupy your attention with a few condensed remarks concerning chemistry itself.

When we regard the origin of the word by which the science is designated, we are led to the inference that chemistry is of ancient date; when, on the other hand, we consider the science as it now is, we are led to the conclusion that the bulk of our chemical knowledge is a recent acquisition. In the one sense chemistry is old, in the other aspect the science is new. If operations involving chemical principles are not some of them of prehistoric origin, it is at least clear that during the dawn of history many useful processes of a chemical nature were practised with good results. They were conducted empirically no doubt; the reasons, such as we should now use to explain what took place in them, were not then understood. They were practised and transmitted much as the arts of India and Japan are conducted, according to traditional formulæ, and transmitted, at the present day. On the other hand, the science of chemistry, with its generalizations (often spoken of as chemical laws), and the mental method whereby we can compute in figures the results of a chemical operation, are of our own times.

To mention in the fewest words certain ancient arts involving chemical principles, I may refer to the art of cooking food, the true and original chemistry, if we accept the etymology which derives the word chemistry from χυμη, a juice or menstruum. Cooking must have been the immediate forerunner of the potter's art; for a fire made on a clay soil, and especially if made in a cavity scooped in the clay surface, would produce of necessity a coarse kind of earthenware, a flat surface or hollow bowl of burnt clay. In the same way, the working of iron, a most ancient art, must of necessity have been attended by the production of slag, and an acquaintance with these fused, ductile, parti-coloured slags must have led up to an acquaintance with glass and enamel. Bronze manufacture, that is to say, the production of an alloy from its constituent metals or their ores, is a remarkable instance of ancient metallurgy. There is a curious metallurgical text in the book of Job—*"Surely there is a vein for the silver, and a place for gold where they

* Job xxviii. 1, 2.

fine it. Iron is taken out of the earth, and brass is molten out of the stone." Molten out of the stone! that is to say, out of malachite and calamine, smelted together with abundance of fuel.

In a pleasing little book by Professor Smith, of Sydney,* there is a pretty full account of the decorations of the interior of early Egyptian tombs, in which, among other occupations, the arts of that ancient people are portrayed with much detail, and which can be interpreted with all the more certainty by aid of the inscriptions accompanying them. The preparation of flax; the vintage; the potter's art,—moulding the clay,—heating the furnaces,—putting in the ware,—and carrying off the finished articles, are all delineated. Glass-blowing is similarly depicted; in one instance six Egyptian artisans are employed at this work, showing that operations were on a pretty extensive scale. There are also figures weighing, melting, and working gold. A goldsmith is seen working with blowpipe and pincers, with articles of jewellery around him; two men are engaged in straining something through a cloth into a funnel and flask: the hieroglyphics show that this is an operation connected with working in gold. Professor Smith asks, can they be squeezing mercury out of gold amalgam?

Besides this kind of evidence, it appears pretty plainly that even in very ancient times a knowledge of the more obvious chemical properties of many natural substances must have prevailed;—of salt,—of natron or carbonate of soda, a natural efflorescence from the soil,—of bitumen and sulphur,—of oils and fats,—of wax and honey, and many other things. The Egyptian method of embalming, for which bitumens were largely employed, clearly involves a principle closely comparable to that of the modern use of carbolic acid as a preservative, [*the lecturer exhibited fish, which, after immersion in solution of carbolic acid, had dried up into mummies,*] and for a last example of this kind of chemical knowledge, I beg to remind you that Solomon the wise illustrates one of his sharpest proverbs by the action of vinegar upon nitre; referring clearly enough to the antagonism of acid and alkali, and to the violent commotion and

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* *Wayfaring Notes: Sydney to Southampton, by way of Egypt and Palestine.* By Dr. John Smith, of the Sydney University. Printed for private distribution. Sheriff and Downing, 256 George-street, Sydney, 1865.

effervescence which ensues on the mingling of *natron* with the acidulous vinegar, the principle, in fact, upon which the ordinary effervescing seidlitz draughts are prepared.

But a certain chemical operation, practised in the earliest ages, conspicuous for the wide extent of its applications in all ages, may be justly regarded as the connecting link between the old chemical arts and the modern science of chemistry; it is the act of combustion,—the ignition and consumption of vegetable and other substances as fuel,—as heat-givers and light-producers. The old dogma of the four elements;—earth, air, fire, and water, imputed to Pythagoras, enforced by Empedocles, was derived from the common phenomena of combustion; finding its crucial test or proof in kindling a handful of wood, or any other ordinary combustible, upon the surface of some cool body. When this is done there rises smoke or air, and flame or fire, moisture or water is deposited on the cool stone, and a little residual ash or earth remains. The wood has been resolved into its co-efficients, factors, or elements, and these are four,—earth, air, fire, and water.*

In this teaching of the Greek philosophers we have a chemistry experimental and theoretical; the phenomena of the combustion are observed, and an explanation, according to the facts and of general bearing, is attempted. This theory of the four elements, regarded as an attempt to explain the composition of material substances and the dissolution of bodies by fire, will appear to our minds as far more truthful than we are apt to consider it to be, if we attach a value to the word *element* according to the sense in which it was then used, and if we attentively regard the state of knowledge of natural facts, at the date when this teaching prevailed. The elements of the Greek philosophers were not elements in the sense in which that term is used by the chemist of the nineteenth century;—and we may humble ourselves by the consideration that the sixty-four elements† of the modern

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* *Lectures and Essays by Samuel Brown.* Constable and Co., Edinburgh, 1868. Vol. I., p. 147.

† For a table of the chemical elements and their combining equivalents, see appendix to these lectures; the numbers there given are according to the *old* notation, which is not yet abandoned by some reliable modern teachers (see Professor Bloxham's Chemistry, Churchill, London, 1867, p. 2). The combining equivalents in our table are those which will be found in use, in most instances, in the literature of metallurgy and applied chemistry: for which reason they are retained here. A card showing the combining equivalents

chemist are also in their turn liable to give way before the advancing tide of future discovery. The old Greek teaching has been utilized, and expanded into the modern doctrine concerning the sixty-four or more chemical elements; and by progressive knowledge, these sixty-four elements (whose elementary nature is suspicious from the mere fact of their numbers, to say nothing of reasons for doubt suggested by minds like those of Dumas and Graham*)—these sixty-four elements may, I say, in their turn give way to a teaching of one foundational basis or stuff, out of which, by some hitherto unexplained system of modifications, all things are made. My object in thus dwelling for a minute on this discarded doctrine of the four elements is primarily because it leads up to chemical ideas which we shall presently consider,—but besides this, that I may point out the progressive nature of chemical science, and how all honest work and faithful interpretation contribute to the final perfected result. I wish to make it plain that the teaching of the four elements is not set at nought by the modern view of sixty-four elementary bodies, but rather that the old teaching is foundational to the new, and that what is good of the old is absorbed into and is still contained in the new. An eloquent modern essayist has told us that "the sciences grow like trees;" in this sense, the teaching of four elements is heart wood, and our modern teaching of sixty-four elements is sap wood: let us bear in mind that our live wood will become heart wood in its turn, the sap then flowing through new channels, while the heart wood remains, and gives strength to the trunk.

The Greek philosophers were not, to any extent, experimental philosophers, and consequently this teaching concerning the constitution of matter underwent no further improvement at their hands; it was not, indeed, until comparatively modern times that a fresh attempt to explain what took place during the burning of a combustible body was made.

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of the elements, *according to the more modern views* included under the term "*unitary notation*," has been published by the Trustees of the Technological Museum. The distinction of the old and new methods, and all the reasons foundational thereto are to be found in most recent Manuals of Chemistry.

*See Faraday's *Lectures on the Non-metallic Elements*. Longman 1853, pp. 160–166. See also *Speculative Ideas respecting the Constitution of Matter*, by the late Dr. Graham, in the *London, Edinburgh, and Dublin Philosophical Magazine*, No. 180, February, 1864.

The names of John Joachim Becher, a German, born in 1635, and George Ernest Stahl, born at Anspach in 1660, are associated with the next step, known as the phlogistic theory. Bodies while burning were considered as parting with phlogiston, or the matter of heat. This phlogiston was thought to be an imponderable element, an entity devoid of the property of gravity, much in the same sense as electricity is spoken of even at the present day. When a body was consumed by burning, the phlogiston went out of it,—so they said,—and the residuum after the burning was regarded as the other component. Inflammable bodies were phlogisticated bodies, the residue after burning was said to be dephlogisticated; this, and the phlogiston or matter of heat, together constituting the original combustible substance. At the time when this new view was first promulgated the art of chemistry had grown to fair proportions; the old knowledge, long before cradled in Egypt, had developed in Arabia, and passed thence to Europe, in part as a kind of awakening pharmaceutical chemistry,—iatrochemistry, full of wild fancies, and not over cleanly in its pharmacopœa (lozenges of dried serpents' flesh, and viper wine, and worse), and partly as the older and genuine alchemy, which stands to chemistry proper much as the grand old astrology stands to modern astronomy. Thanks to the good work of the earlier alchemists, Stahl's hypothesis of phlogiston was addressed to a range of chemical facts far, very far more extensive than that known to the Greek philosophy: it offered an explanation, not only of ordinary combustion, but also of chemical changes, such as the conversion of metallic lead into litharge, and of quicksilver to oxide of mercury, by heat and simultaneous exposure to the atmosphere. But the " sciences grow like trees," and the phlogistic theory broke down under the searching investigations of the highly-gifted Lavoisier.* He employed the balance as an instrument of research, and found that the calces or oxides of tin, lead, &c., were heavier than the metals from which they were produced. He showed that the oxide of mercury was resolved by heat into mercury and a gas, and he showed when metallic tin was oxidized or converted into a calx, by heating in a capacious glass vessel, hermetically sealed and containing atmospheric air, that notwithstanding the change of tin into calx, the vessel and its con-

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* *Thomson's History of Chemistry.* Colburn and Bentley, London, second edition, page 94, *et seq.*

tents neither gained nor lost weight. Lavoisier's work led to the understanding that although the original form of the combustible is destroyed by burning, the combustion is an act of chemical combination, and not a mere resolution of the substance into phlogiston and a dephlogisticated ash.

The use of the balance by Lavoisier in his experiments has proved a turning-point in chemical science, which since his time has addressed itself to ponderable matter alone, *seeking always for an equation in which the products of any chemical change, whether solids, liquids, or gases, are collectively exactly equal to the original matters concerned.* The modern chemistry,—statical chemistry,—accounts for all changes of a chemical nature to this extent, namely, that the products of the change, whatever their state, in whatever physical condition they present themselves, are collectively exactly equal in weight,—exactly equal, according to the test of gravitation, to the sum of the original matters in which the chemical change is induced. The chemical operation is always an equational operation, in the sense of what can be weighed in a pair of scales.

But science is always "growing like a tree," and the adoption of the balance, at first useful in this sense of accounting for the quantities of chemical changes, that is to say in analysing compounds, in due course produced a very remarkable outgrowth.* Facts first observed by Dr. Bryan Higgins, and announced by him as early as 1786, were afterwards independently observed by Dr. Dalton, the great Quaker chemist, and consolidated into what has been called the atomic hypothesis; a doctrine in which hypothetical views concerning the ultimate constitution of matter are raised out of the solid groundwork of chemical experience. We need not on this occasion expend time on the consideration of Dalton's admirable hypothesis; but as the facts upon which it is based belong to the very alphabet of modern chemistry, we shall find a few words concerning them much to our present purpose. In speaking of what are called combining proportions, the mind is apt to revert to Dalton's conceptions of the relative weight of atoms of different kinds of matter, but in what is about to be said on the subject the aim will be that of bringing forward simply the facts of the case.

* See *Life of Dalton*, by Dr. Henry. Printed for the Cavendish Society by Harrison and Sons, St. Martin's Lane, London, 1854—p. 71, *et seq.*

Continuous appeal to the balance by the chemist, soon taught him that although he might mix matters together in every proportion at will, in effecting their combination (a very different thing from mere mixture) the proportions in which they are combined is not at the option of the experimenter, but is fixed and unalterable, and in accordance with the nature of the matters so combined. As the result of work with the balance, the chemist of to-day is enabled to recognise sixty.four different kinds of original or elementary matter—sixty-four different sorts of matter, each of which he feels bound to accept as a species, *sui generis,* for the reason that it has hitherto resisted all attempts to resolve it into more simple parts. I must very briefly, and generally revert to the combining aptitudes of these elements, of oxygen, chlorine, bromine—of nitrogen, phosphorus, arsenic—of potassium, lead, silver, platinum, and the rest of them—and I now therefore crave your patient attention to what I have to place before you, in a purely introductory sense, concerning this linch-pin or key-stone of the chemical method. You see here a list of these elements, and you observe that numbers are attached to each of them; these numbers represent the proportions by weight in which they respectively combine. It will be more precise to state that, regarded in reference to each other, these numbers are the least proportions by weight of the ponderable matter of each kind, as estimated by the balance, in which they can combine. As far as these sixty-four elements are apt to enter into combination with each other, their proportions of combination appear, from countless observations, to be in precise accord with the numbers here given; and although a body may combine with another in two, three, four, or more proportions, generating two, three, four, or more definite compounds, these less simple combinations have always reference to the numbers attached in this list to each of the elements. Six of carbon with 8 of oxygen by weight, combine to form 14 of carbonic oxide; 6 of carbon with twice 8, or 16 of oxygen, form carbonic acid; 12 of carbon, or twice 6, with 24 of oxygen, or 3 times 8, form 36 parts of dry oxalic acid. These numbers, in the sense of ponderable matter, as we can determine it with weights and scales, represent the amounts in which each of these elements can combine; they represent the smallest amounts in which it is possible for them to combine;—the respective weights of their atoms according to the views of Dalton: and when any of them combine so as to

form more than one compound with any other element, they combine in twice, thrice, or some other multiple, by a whole number of the proportional weights attached to each of them in the list.

Thus chemistry has become a science of numbers,—a science dealing with precise quantities; and the chemist can calculate with precision, before putting these elements together, in what proportion to place them under the conditions of combination, so as to obtain the required amount of the desired compound, and so as to have no overplus of either constituent. And of any given combination he can, by calculation beforehand, ascertain what the products of its dissolution or decomposition will be;—what proportion of each he will obtain by dissecting it.

What has just been said concerning the combination of one element with a second, applies equally well to the formation of compounds of three or any larger number of them, and in the combination of one compound with another, the same principle holds good throughout the whole range of chemical substances. The collective weight of the integers, or combined atoms, in any given compound, is the weight of the least combining proportion of that compound; so that these figures are foundational to the computation of all chemical operations,—to instances innumerable, and to chemical transformations of the most varied kind.

A few words will distinguish these chemical changes from mere physical changes; generally speaking, all changes in the state of bodies unattended by alteration of composition belong to the province of physical science, while all changes in which an alteration of composition occurs, belong to chemistry. To melt ice into water,—to boil water into steam, are purely physical operations, altering the physical state of water; the steam will again condense into water, the water will again freeze into ice; we may repeat the round of these operations indefinitely, and we have, throughout, water, in its three different modifications of ice, fluid water, and vapour. On the other hand, by a chemical operation water is resolved into two gases of very opposite characters which cannot be liquified or solidified, as may be done with the vapour of water itself. To take another simple example;—if limestone be sufficiently heated in a closed vessel, it is melted into fluid marble, but nothing is separated from it,—it suffers a purely physical change; but when limestone is heated in a space open to the atmosphere, it is chemically decomposed, its

elements are dissociated, its carbonic acid is distilled out of it, and quick lime remains. Refer this chemical change to the numbers in our table of the elements,—calcium, 20 parts, with oxygen, 8, form 28 parts of lime, and carbon, 6, with twice 8, or 16 parts of oxygen, form 22 parts of carbonic acid: when 50 parts of limestone are burnt in the kiln, 22 parts of carbonic acid are expelled, the loss of weight is 22 parts in 50, and 28 parts of lime remain. I have spoken of these combining equivalents as forming the keystone of the chemical method; it must be added that there are many other generalizations in the science, and that these collectively constitute the basis of a rational chemical method, enabling the inquirer to arrive at results by a road which is short and safe, and in all respects preferable to blind and unguided wanderings in the regions of the unknown. It is true that the facts of chemistry are multitudinous, but a knowledge of these methods of chemistry, as I have instanced them by this slight reference to the combining proportions of the elements, is within the reach of any of us. A first glance at the formulæ displayed, on opening a chemical work may discountenance a personal attempt; it may impress the individual very much as an architect's plans suggest at first sight the largeness and intricacy of the builder's work; but as when the mason has truly laid a few courses all appears straightforward enough, so, as soon as a careful chemical groundwork has been laid in, the sense of the difficulty of building up to any required height of chemical proficiency is thereafter dispelled.

But, recurring to the decomposition of water into eight parts by weight of oxygen and one part by weight of hydrogen, I wish to call your attention to a fact expressed by the diagram now exhibited, [*these lectures were illustrated throughout by diagrams and experiments*,] namely, that there is also a simple proportion in the measure,—in the cubic dimensions, of the gases of which water is composed. Oxygen is exactly sixteen times heavier than its own bulk of hydrogen, so that eight parts of oxygen to one of hydrogen, by weight, are equal to two measures of hydrogen to one of oxygen, by bulk or cubic dimensions; and by this decomposition of water by an electric current, as depicted, connecting this instrument, or voltameter, as it is called, with a voltaic battery for the purpose, we obtain an example of what prevails concerning the combination of gases and vapours generally, namely, that the

volumes in which they combine bear even simpler relations to each other than their combining weights. Thus has arisen a method of chemical computation by volume,—a volumetric chemistry, in which the weights of combination are computed from measurement of bulk; a method of great significance, and applicable to all simple and compound bodies, such as are known to exist in the gaseous state.

There is another foundational fact exemplified when water is decomposed; it is of a character so important as to induce me to say a few words concerning it. In the voltaic battery the electric disturbance takes place at the surface of the zinc, dissolving in the battery cell; where it occasions what is called a current of positive electricity, which passes through the acid fluid to the platinum plate, and along the pole or wire attached to the platinum through the fluid in the decomposing cell or voltameter, as it is called, to the opposite pole or wire, by which it returns to the zinc. Faraday has called the poles or wires by significant names; the wire attached to the platinum, by which the positive current goes up into the voltameter, he calls the anode (the road upwards,—*ανα*, upwards, and *οδος*, a road); the wire connected with the zinc, by which the current returns from the voltameter to the battery, he has named cathode (the road downwards,—*κατα*, down, and *οδος*, a road or way). It happens that the oxygen of the water decomposed is always eliminated at the anode, or pole where the current of positive electricity enters the fluid in the decomposing cell; and the hydrogen is similarly eliminated from the cathode, or pole at which the positive current returns down from the voltameter to the battery. If hydrochloric acid, instead of water, is similarly decomposed by a voltaic current, the chlorine is set free at the anode, and the hydrogen, as before, at the cathode; — and this opposite relation of these elements led the great Berzelius to found a mode of classification upon it,—an electro-chemical classification, which has proved of immense value to chemical science. The elements were thus classified as electro-positives and electro-negatives, in a comparative sense and in reference to each other; a given element being electro-positive to another element, while it is electro-negative to a third. In salts easily separable into acid and base by a voltaic current, the acid shows as the electro-negative element, or anion, at the anode, or positive pole; and the base, as the electro-positive, or kathion, at the cathode, or negative pole. If caustic soda is decomposed by the battery, the

oxygen, the electro-negative element, appears at the anion or positive pole as usual, and the metallic sodium appears at the kathion, where the hydrogen in the former instances showed itself. Hydrogen and the metals appear at the same pole. There is good reason for regarding hydrogen as a metal,—a gaseous metal, just as mercury at common temperature is a fluid metal; indeed, hydrogen in all its chemical relations plays the part of a metal, and, in brief, this decomposition of bodies by an electric current throws a light upon the aptitudes of the elements and their compounds, affording great assistance to the interpretation of chemical changes. The terms positive and negative elements are perhaps not quite satisfactory, and Faraday's distinction of anions and kathions has not come into general use; the division into chlorous and basylous elements is possibly on the whole more suitable, chlorous bodies being those which, like chlorine, iodine, and oxygen, appear at the anode, and the basylous bodies, including hydrogen, the metals generally, and the bases of salts, being those which are in a chemical sense basic, and appear at the kathode of the voltaic circuit.

The strongest chemical combinations occur between those bodies which are most widely different in their electrochemical relations, between the most distinctly chlorous and the most basylous,—the weakest between those of similar electro-chemical aptitudes; thus chlorine combines with potassium, a strongly basylous element, to form chloride of potassium, which may be sublimed at a red heat without decomposition; while there are compounds of chlorine with oxygen (both strongly chlorous elements) which are so unstable that the heat of the hand, or a slight jar or shake, is sufficient to shatter them into their original elements. The chemical combination of one element with another,—of one chemical compound with another, or with an element, requires that the things combining shall be different, the chlorous combining with the basylous, or the electro-positive with the electro-negative, or, to use Faraday's terms, the kathion with the anion. For stable combinations the constituents must not be too near akin, for it is the opposite natures which attract each other.

One concluding explanation will complete all that I have to say at present concerning chemical combination. When one body combines with another, there is a kind of mutual interpenetration of the two different masses of matter.

When 23 parts or one equivalent of sodium combines with 24 parts or three equivalents of oxygen (more than its own weight) and six parts of carbon, the resulting fused carbonate of soda occupies actually less space than that occupied by the original metal,—there results 55 parts by weight of carbonate of sodium, occupying less space than the 23 parts of solid metallic sodium which it contains. Facts of this nature, and facts of other kinds, appear to show that there are open ways between the particles or atoms of the most solid bodies, and these interspaces appear to be the high roads of chemical exchange, wherein each atom finds its associate. Concerning the real size of these atoms of matter, or what they are, or what relation they bear to the space between each in the most solid bodies, we know nothing; the microscope is far too shallow in its powers for showing us anything concerning them; for anything we know to the contrary, there may be relatively as much space between the ultimate atoms of solid iron and gold as there is between the fixed stars in the firmament.

In order to acquaint ourselves with the manner in which a chemical operation becomes applied as a manufacturing process, let us, in the first place, ascertain by examples (purposely selected on account of their simplicity) concerning the nature of a chemical operation. Here is sodium; burnt by placing it in contact with water, the metal seizes the oxygen of the water, liberating the hydrogen of the water as gas. Hydrogen plays the part of a metal in all its chemical relations; and this first example of a chemical operation consists in the displacement of hydrogen by sodium.* If we burn a known weight of sodium in a small quantity of water, we can afterwards find out exactly how much soda is produced by trying how much sulphuric acid is required for saturating and neutralizing the alkaline character of the soda solution; it requires 40 parts of real sulphuric acid to neutralize 31 parts of soda. I take 23 grains of sodium (1 equivalent expressed in grains), I plunge it into water and collect the hydrogen; it should disengage one equivalent—that is to say, 1 grain of hydrogen, equal to 46·73 cubic inches of the gas, measured at 60 degrees Fahrenheit, and 30 inches barometric pressure; for the bulk of gases is affected by both temperature and pressure. I

* For a pictorial illustration of this experiment, see *Bloxham's Chemistry*, 1867, p. 23.

have marked the jar for this quantity; you see how near is our result, notwithstanding the off-hand procedure. Our operation, expressed as an equation, stands thus:—

1 equivalent of sodium, or 23 grains + 1 equivalent of water, or 9 grains = 1 equivalent of soda, or 31 grains + 1 equivalent of hydrogen, or 1 grain.

We take of sodium and water together 32 grains, and we obtain of soda and hydrogen together 32 grains.

I add another example of the chemical operation. In oxygen I burn carbon, and I obtain carbonic acid. I add lime water to my gaseous product, and the lime and carbonic acid together form carbonate of lime; 50 parts of carbonate of lime are exactly equal to 22 of carbonic acid; it is easy to collect and weigh this carbonate of lime, also to show that every 6 parts of carbon consumed, require two equivalents, twice 8 of oxygen. Oxygen twice 8, or 16 parts, and carbon 6 parts, equal carbonic acid 22 parts; and this carbonic acid, 22 parts, with 28 parts of lime, equal 50 parts of carbonate of lime. [*Illustrated by the combustion of the diamond and of charcoal in separate vessels of oxygen gas, with the after addition of lime water to the gaseous products of combustion, in each instance.*]

This operation enables us to calculate what would be required, and what produced, in the combustion of any amount of carbon. Thus, the great diamond, the Koh-i-noor, in its recut state weighs $102\frac{1}{4}$ carats,—each $3\frac{1}{6}$ grains, or 323·79 grains. It would require 2495·4 cubic inches of oxygen to consume it; and re-precipitated by lime-water, after combustion, it would form $2698\frac{1}{4}$, or 6 ounces $73\frac{1}{4}$ grains avoirdupois of chalk or whiting. That conversion would be a simple chemical operation, and would stand thus:—Koh-i-noor, of pure carbon, equals carbon 323·79 grains, plus oxygen in the proportion of two equivalents, equal to 863·44 grains, or 2495·5 cubic inches; these are together equal to the product of combustion, namely carbonic acid 1187·23 grains, or 2495·5 cubic inches, (the same in bulk in fact as the oxygen consumed). This carbonic acid, 1187·23 grains, with its equivalent of lime, 1511·02 grains, added as lime-water, equals 2698·25 grains of carbonate of lime or whiting. There is a little carbonic acid in atmospheric air —about four parts in 10,000; a simple calculation will show that there is one Koh-i-noor, that is to say, the carbon equal to it, in the air of an apartment fourteen feet square and fourteen feet high.

The chemist can always account for these changes, even the most complex of them, by showing that the sum of his products is equal in weight to that of the original re-agents. But there are other matters which he cannot with certainty control or predict; he cannot with nicety predict the physical character, or even the chemical properties, of any new and hitherto unknown compound which he is about to generate; and in many cases he may not succeed in effecting some specific combination, although he taxes his ingenuity to the very utmost in the attempt. But what one chemist fails in, another, more fortunate in some new device, may manage; and thus the pursuit, although involving great certainty in all that concerns quantities, has in other respects enough uncertainty to make it full of speculation and interest; the more so as these new compounds are not only surprising on account oftentimes of their beauty, or of unexpected and remarkable properties, but because also they occasionally prove valuable, almost beyond calculation,—"beyond the dreams of avarice,"—in the arts of life.

But to apply a chemical operation so as to make it a working process in the arts,—so as to make it a chemical industry, requires, in most instances, no small effort. We have now a fair idea of a chemical operation, and in what it consists, let us in the next place endeavour to ascertain the nature of a chemical process, that is to say, of a process in the arts involving chemical principles, and conducted according to its chemical bearings. Let us take two or three instances, commencing with a simple example, and afterwards proceeding to those which are somewhat more complex.

For our first instance let us take a glance at the sulphuric acid manufacture,—for many reasons one of the most important of all the chemical arts. More than four centuries ago, the alchemist, Basil Valentine, subjected green vitriol, as it was then called (a sulphate of iron), to distillation, and obtained an acid liquid which he called oil of vitriol. That process of making the acid is even at the present day in limited use for generating a particularly strong acid, at Nordhausen, in Saxony. The same grand old alchemist (Basil Valentine) also obtained an acid which he named "oleum sulphuris per campanum," by burning sulphur under a glass bell over water and evaporating the acid liquid thus obtained. The next step was that of burning sulphur with nitre over water. There being an increased

demand for the acid, Dr. Roebuck, about 1770, substituted chambers of lead for the glass vessels hitherto employed. These chambers, from that date, have increased in size, following the continually increasing demand for the acid, until at the present time upwards of 100,000 tons of it are annually produced in Great Britain. Increased demand has produced gradual decrease of price; from about half-a-crown an ounce, the price at which the original "oleum sulphuris" appears to have been sold, the price fell to about half-a-crown a pound for acid made under the bell by burning sulphur and nitre together: when leaden chambers were introduced the price became a shilling a pound, and now it is as low as five farthings.

In the manufacture of oil of vitriol, two compounds of oxygen and sulphur are concerned,—namely, the sulphur*ous* acid (SO_2), composed of sulphur, 1 equivalent = 16, and oxygen, 2 equivalents, or twice 8;—of equal weights, therefore, of sulphur and oxygen. There is also the sulphur*ic* acid, which in its water-free state consists of sulphur, 1 equivalent, and oxygen, 3 equivalents;—16 parts of sulphur to 24 of oxygen, which with 9 parts, or 1 equivalent of water, form 49 parts, or one equivalent of oil of vitriol of commerce. The part played by the nitre used in the manufacture is remarkable. When sulphur is burned in air alone, sulphurous acid is the chief product, a solution of this acid after a time absorbs oxygen, and becomes sulphuric acid; but a more expeditious plan than this is required on the large scale, and so the nitre is used. The following are the principles involved in the use of nitre; when sulphurous acid acts upon nitric acid in the presence of water, sulphuric acid and nitric oxide are formed:

$$3\ SO_2 + HO, NO_5 + 2\ HO = 3\ (HO, SO_3) + NO_2\ *$$

Nitric oxide in contact with air combines with the oxygen of the latter, forming nitric peroxide NO_4. If nitric peroxide is brought into contact with sulphurous acid and water, it is again converted into nitric oxide, and sulphuric acid is simultaneously generated.

$$NO_4 + 2\ SO_2 + 2\ HO = NO_2 + 2\ (HO, SO_3)$$

The nitric oxide performs the office of a carrier of oxygen from the air, handing it over to the sulphurous acid; so that, theoretically speaking, an unlimited quantity of sulphurous

* The reader is referred to the symbols attached to the elements in the table of elements appended to these lectures for elucidation of these equations; also to the chemical text-books.

acid, supplied with air and water, might be converted into sulphuric acid by a limited quantity of nitric oxide. In practice, however, there is a limit, requiring replenishment of the nitric fumes. Four-fifths of the bulk of the air passing into the sulphur burner, and thence to the chamber, is nitrogen, which plays no part in the process; the continued exit of this nitrogen is a cause of waste of the efficient gaseous contents of the chamber, and this waste of the nitric fumes must be made good. To work the chamber with the least possible waste of materials is the triumph of the vitriol-maker's art.*

The mode of procedure on the large scale is simple enough; the sulphur is burnt on an iron plate in a brick stove, with a carefully regulated supply of air. Over the burning sulphur are placed pans containing nitre (nitrate of soda) and sulphuric acid, for evolution of the nitric acid vapour. The fumes from the burning sulphur, as well as those from the nitre pans, are conveyed into the lead chamber,—a large hall, with ceiling, walls, and floor of sheet lead, often of a capacity of fifty, or even one hundred thousand cubic feet. Into this chamber is also conducted a jet of steam, and a shallow layer of weak acid occupies its floor. The weak sulphuric acid formed in the chamber condenses on its inner leaden walls, and trickles and rains down to augment that which is in the bottom; and this weak acid is run off to evaporating pans of sheet lead for concentration. As the acid grows stronger the temperature of evaporation rises higher and higher, until a drop of water thrown on the hot acid sputters and hisses as it would do on red-hot iron. The acid heating up in this way, a point is eventually arrived at, at which the lead would give way, if the evaporation were further pushed. The acid is now drawn off from the lead pans, and weighs 17½ pounds per gallon; in other words, it is one and three quarter times as heavy as its own bulk of water. For the final concentration, some other kinds of vessels than those of lead must be adopted. Glass stills heated on sand baths have been employed; afterwards costly platinum alembics came into use,

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* Engraved representations of the vitriol chamber may be seen in *Roscoe's Lessons in Elementary Chemistry*, and in other similar manuals. See *Richardson and Watt's Technology*, Bailliere, London. See also Dr. Hoffman's *Report on Chemical Products and Processes*. International Exhibition, London, 1862: this admirable document is a brilliant review of the entire range of the chemical manufactures.

offering great facilities for despatch, but costing about a thousand pounds each, and therefore objectionable from their costly nature. Recently, in England, glass stills have once more returned into use, although in France and elsewhere the elegant platinum vessels hold their position.

A feature of interest concerning one of the constituents of the acid, namely, the sulphur, must not be passed over. Prior to 1838 almost all the sulphur employed in the manufacture was the native sulphur of Sicily: the Neapolitan Government tampering with the free exportation of their sulphur to the manufacturer, led him to seek for some other source of this, to him, all important mineral. This action of the Neapolitan Government was not the only cause at work, but from their suicidal policy and other causes the vitriol-maker was forced to look about him, and thus the use of iron pyrites, a compound of two equivalents of sulphur and one of iron, as a source of sulphur for vitriol-making, originated. At this present date the great bulk of the oil of vitriol of commerce is obtained, not from Sicilian or other form of native sulphur, but from pyrites, which when burnt in a stove evolves sulphurous acid copiously; this sulphurous acid is oxidized in the lead chamber, and after the usual concentration passes into commerce as oil of vitriol.

Let us pass from this, to other examples of applied chemistry. There is a rare—indeed precious—mineral called lapis lazuli; it is of a magnificent blue colour, often dotted over with golden starry specks of pyrites, its colour is preeminently azure, and in the powdered state it has long been coveted by artists as the only pigment available for representing, with fidelity, the blue sky. Its price was almost prohibitive, for it was worth nearly its weight in gold. Analysis has shown it to be essentially a silicate of alumina, soda, and lime, containing also sulphide of sodium. Its blue colour has been always a puzzle. In 1824, the Societe d'Encouragement pour l'Industrie Nationale de France offered a prize of 6000 francs for a practical method of preparing artificial ultramarine. The question was one involving a chemical operation, and it was solved independently by two chemists, M. Guimet and Professor Gmelin. Gmelin published his method, and, in consequence, the once costly ultramarine pigment may now be bought for as little as a shilling, or even tenpence a pound. Posting bills are now printed in azure of a tint purer than anything within the ordinary reach of artists half a century ago. Fifty thousand

hundredweights of this artificial ultramarine were manufactured in 1855.

But the chemistry of dyes and pigments affords examples even more striking than ultramarine. There are the coal tar dyes, a creation within the memory of almost all of us, dating as recently as 1856. Coal tar, a black, fetid, sticky semi-fluid, equally repulsive to sight, smell, and touch, one of the most noisome, as it is one of the most abundant, and (heretofore) troublesome of the gas manufacturer's waste products, has given rise to a whole spectrum of dyes of superb brilliancy, and a purity comparable to the hues of the rainbow itself.* Chemistry has shown that this coal tar, though "ugly and venomous, bears yet a precious jewel." When tar is distilled, naphthas and tar oils and solid hydrocarbons come over, and pitch remains in the still. The products distilled from tar have been for many years regarded by chemists as objects of very great interest and promise; and it has been for many years understood that in these products (the naphthas and tar oils) many different compounds are commingled. Chemists have spent no small amount of effort for separating these compounds from each other, often with success, but, to speak out plainly, the subject of the components of coal tar is at the present time very far from exhausted. Some of these tar constituents, when separated in a state of complete purity, are remarkably beautiful compounds. Benzol is one of these; it was discovered by Faraday, about 1825, and was afterwards identified as a constituent of coal tar by a promising young chemist, Mansfield, in 1849. Poor Mansfield unfortunately lost his life by an accident with his stills, but his work has since tesselated in with that of other chemists devoting themselves to the same line of study. It had been observed by many chemists that aniline, another constituent of coal tar, was apt under certain influences to acquire a blueish and purplish, and even crimson colouration. Perkins, a young chemist of the same school as Mansfield, took the first step in reducing this fact to commercial account; to him belongs the credit of having first separated the substance to which the purple colouration was due, and of having fixed it on woven fabrics. This first product was called aniline violet, or mauve. It was the precursor of a series of discoveries of other coal tar dyes—reds, blues, yellows, greens, and blacks.

* Dr. Hoffmann's Report.

The discovery of a new tar dye was soon regarded as a certain road to fortune, and, of course, the great rewards attending success in producing these new colours proved a stimulus to research.

In the report on the coal tar colours shown at the great Paris Exhibition, by Dr. Hoffmann and his colleagues, there is an amusing story of a somewhat empirical discovery of an aldehyd green; the story has a moral to it, and as it is a short one I think it will not be out of place.—"Aldehyd Green. This green was patented in October, 1862, by M. Usébe. Its discovery some months before is due to a combination of circumstances sufficiently curious to deserve recording, although such occurrences are not unexampled in the history of scientific progress. A dyer, like all others of his craft at that time, was busily occupied experimenting with the aniline dyes. Amongst other things he tried a reaction which had been described by M. Lauth, at the end of 1861, videlicet, that of aldehyd on a sulphuric solution of aniline red. In this reaction a substance is produced which gives to solutions an extremely evanescent blue colour. M. Lauth had given up all idea of utilizing this blue colour in practice; and M. Cherpin endeavoured to fix the same colour on silk or wool, with similar want of success. His attempts, although fruitless, were incessantly renewed, exhausting his purse, but not his patience. One day, however, discouraged at the want of success attending some recent experiment on which he had founded great hopes, he was on the point of relinquishing the attempt at conquest over this fugitive blue, when the idea struck him to confide his troubles to an old friend, a photographer. 'A trouble shared is a trouble halved,' says the proverb; Cherpin proceeded to test this saying, and experienced the reward of his perseverance and his confidence in the consolations of friendship. He found his photographic friend, and confided to him the history of all his hopes, his experiments, and his fruitless results. 'Fix the blue?' said his friend. 'Is that the only difficulty? Why, it's the *easiest* thing in the world! Have you tried hyposulphite of soda?' 'Hyposulphite of soda? Mon Dieu, no! Do you think it will fix my colour?' 'Of course it will. Don't you know that hyposulphite of soda is the fixing agent par excellence, and that when we want to fix anything in photography that is the substance we always employ?' Happy he who possesses faith! Cherpin tried hyposulphite of soda, and his joy and admiration of the chemical

knowledge of his friend may be imagined, when he saw his blue colour metamorphosed into a splendid green—this time perfectly stable. It is scarcely necessary to add that the mode of action of hyposulphite of soda in this case is entirely different from its photographic action, and that it would be quite impossible to predict the one by knowing the other." Then Dr. Hoffman suggests a moral. "This anecdote contains a moral. It shows, not the result of chance, for that is common to all the world—for where is the discovery to which chance has not more or less contributed?—but it shows the power of the will, the power of perseverance. Chance only favours two kinds of persons; those sufficiently instructed or endowed with talents eminent enough to observe it, to seize it, and to profit by it: and those who, by patience, perseverance, and the power of their will, force it in time to become useful to them."

These processes of manufacturing the tar dyes are of a very refined character; a glance at the method will show this. Benzol* is a hydrocarbon, a compound of carbon and hydrogen; it is first converted into nitrobenzol, (a compound having a resemblance to oil of bitter almonds) by regulated treatment with nitric and sulphuric acids. Toluol, another hydrocarbon very similar to benzol, and which accompanies it in the samples used, is converted into nitrotoluol, the presence of which along with the nitrobenzol is essential to the production of the tar dye.

$$\underbrace{C_{12}\,H_5,\,H}_{\text{Benzol.}} + NO_5 = \underbrace{C_{12}\,H_5\,NO_4}_{\text{Nitrobenzol.}} + \underbrace{HO}_{\text{Water.}}$$

The oil of vitriol added with the nitric acid does not enter into the combination, but by its affinity for water it merely fortifies the nitric acid for the work.

The nitrobenzol is next converted into aniline, a kind of compound ammonia—

$$\left.\begin{matrix} C_{12}\,H_5 \\ H \\ H \end{matrix}\right\} N$$

phenyl ammonia, as it is called, which exists to some extent already formed in coal tar, but which it is preferable to prepare from nitrobenzol, by adding to it two equivalents of

* See *Handbook of Anilines*, by Reimann, edited by William Crookes, F.R.S.—London, Longman, 1868.

hydrogen, at the same time extracting four equivalents of oxygen, thus:—

$$\underbrace{C_{12}H_5NO_4}_{\text{Nitrobenzol.}} + 6H = \underbrace{C_{12}H_7N}_{\text{Aniline.}} + 4HO$$

To effect this change, the nitrobenzol is submitted to the reducing action of iron filings in contact with acetic acid; or to explain with a little more detail, in this operation acetic acid and iron are transformed by the decomposition of water into acetate of protoxide of iron, which under the influence of heat and the oxygen of the nitrobenzol becomes acetate of peroxide of iron;—the peroxide of iron being an oxide which contains more oxygen than the protoxide or first oxide. This last acetate is finally robbed of its acetic acid by the newly-generated aniline, leaving the iron oxide in combination with water as a hydrated peroxide. The aniline, which is a base similar to ammonia, combines with the acetic acid, but the resulting acetate of aniline is split up by the after-distillation, which affords a very dilute solution of acetic acid and crude aniline, which latter separates as an oily fluid.

The final operation, that of converting the aniline and toluidine into colouring matter, that is to say, into rosaniline, is a process of oxidation. Several modes are available; that with arsenic acid may be instanced,—the arsenic acid parts with a portion of its oxygen in favour of the aniline, converting it to rosaniline, or magenta, thus:—

$$\underbrace{2(C_{14}H_9N)}_{\text{Toluidine.}} + \underbrace{(C_{12}H_7N)}_{\text{Aniline.}} + \underbrace{3(AsO_5)}_{\text{Arsenic Acid.}} =$$

$$\underbrace{C_{40}H_{19}N_3}_{\text{Rosaniline.}} + \underbrace{3(AsO_3)}_{\substack{\text{Arsenious}\\ \text{Acid.}}} + \underbrace{6HO}_{\text{Water.}}$$

What I have offered in explanation is a mere sketch of this class of operations. The key to what is done in each stage of processes of the kind, is afforded by analyses of the products, ascertaining how much carbon, hydrogen, nitrogen, &c., they contain. The chemical equation between the materials employed and the products obtained is always kept in view; and to show the necessity of this, it may be mentioned that in one of the most successful of all the establishments for the manufacture of these tar dyes (all the firm being chemists) one of the partners, a chemist of the

highest endowments and skill, was told off to attend exclusively to chemical research incident to their operations.

But the most wonderful story concerning these artificial dyes remains to be told. Madder root has been for a long time one of the right hand auxiliaries of the calico-printer and of the dyer; it yields, under skilful treatment, a variety of tints, including the famous Turkey red. It contains more than one tinctorial constituent, but alizarin is, of all, the essential constituent upon which its economic value chiefly depends. A long series of chemical investigations has led to the artificial formation of this alizarin, and I have the pleasure of presenting to the notice of all assembled here samples of stuffs printed with this artificial alizarin, the alizarin of a new dynasty.* I desire that facts such as I endeavour to place clearly before you should prove their own interpreters; but, nevertheless, I am tempted to say that, to my mind, this production by artificial means, based on what is sometimes spoken of as an abstract study,—based on abstruse chemical researches,—that this production, from coal reclaimed from the bowels of the earth,—from the debris of a vegetation immensely remote in time; that the production, I say, of a dye stuff identically the same as that obtained from roots of plants now growing, and at this present time bathed in the day's sunshine, and drawing sustenance from the soil;—that this, our artificial product, should jostle and oust the madder dyes from their place in commerce, is one of the most speaking instances of the power and fruition of methodical chemical pursuits.

I feel that I have taxed your attention this evening with an array of chemical details; I conceive that there must be a considerable strain upon the attention where the ideas presented are of an unfamiliar kind; but it is right that I remind you how little I have troubled you with my own reflections, and how much I have allowed the suggestive facts to speak for themselves. The examples selected have been submitted to your judgment merely as specimens. If I can tempt any of this audience to make acquaintance with chemistry, I promise that they will find the subject of continually increasing interest as they proceed; and I venture to assert that even the abstruse formulæ of chemistry will prove of high interest to such as have sufficient mental

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* See *Journal of the Chemical Society of London*, Series 2, Vol. VIII., May, 1870; "Perkin on Artificial Alizarin."

metal and daring to make acquaintance with them. I trust that my examples will show that the higher branches of chemistry are not mere abstractions; that, on the contrary, they are the real, solid, deep foundations of the visible, palpable chemical arts. Deeply seated, these foundations are unseen, and therefore apt to escape consideration; but they are there, and they uphold a grand superstructure, and their strength is equal to all that human intelligence and industry can ever rear upon them.

Dr. Johnson said of the Greek language, that it was like lace—every one acquired of it as much as possible. Speaking to the Victorian manufacturer and artisan, I advise each one of them to covet as much chemistry as he is able to obtain. The means for practical instruction are preparing in this Institution, and I trust that before very long the results of this kind of knowledge, disseminated through the colony, will be apparent in the flourishing condition of our chemical arts.

LECTURE II.

CHEMISTRY APPLIED TO AGRICULTURE.

DELIVERED BY GEORGE FOORD,

ON 29th SEPTEMBER, 1870.

THIS evening it will be my task to present a sketch of the relations borne by the science of chemistry to the most ancient art of agriculture, and to show how chemical facts and methods are available for assisting in their respective pursuits the cultivator of the soil, and the grower of stock. Favoured by your indulgence, it will be my aim to treat the subject in its simplest, but also in its most practical aspect, as though the grower of cereals or root crops, the cultivator of the vine, the sugar planter, or the sheep farmer, had come to-night to ask "What benefit he might expect from the acquisition of a little sound chemistry?"

I may add, also, that for economy of time, my observations concerning the origin of what is called Agricultural Chemistry will be few indeed.

We need look back no further than the commencement of the present century. Chemistry had then become so rich in facts, its resources and powers had become so greatly increased, it was becoming useful in so many other directions, that its applicability for the improvement of agricultural practice began at that date to dawn upon the human mind. Analytical chemistry was becoming a powerful machinery, and the achievements of Lavoisier, De Saussure, Berthollet, and others, had prepared the way for the zealous labours of our own Sir Humphry Davy. The time had arrived, and Davy's celebrated lectures on Agricultural Chemistry (referred to by Liebig as "immortal") were delivered during the years 1802 to 1812. Perhaps Davy's ardour and eloquence did as much as the available knowledge at his command towards laying a foundation and fairly starting the work; be that, however, as it may,

this work has certainly gone on uninterruptedly and with vigour from Davy's time to this present, and Germany, France, and England have each contributed a fair and honourable share to the result as it now is. The collective effort for winning all that has been achieved during the seventy years in this department of human knowledge has been immense, but the fruits of so much mental toil are obviously more than a recompense for the outlay; indeed, the whole civilised world has been permanently benefited by the results. In seventy years these workers, Davy, Liebig, Mulder, Boussingault, Gilbert and Lawes, Way, and a host of others, have by their combined effort solved the problem of making two blades of grass or ears of wheat spring up where only one could be grown before. Chemistry, during the period mentioned, has done very much for agriculture, but very much also remains still to be done, so that the pursuit at this hour promises rewards to the earnest chemist quite as great as those forming the inducement at the outset. It will be my endeavour in what follows, to exemplify the present state of our knowledge—the chemistry applied to agriculture as it at present stands, and I propose that we commence by paying attention to a few general facts concerning the chemistry of the soil.

Of the entire surface of our globe about three-fourths is submerged beneath the ocean; the remaining fourth, amounting in all to about fifty-one millions of square miles, is dry land, partly raised up in mountain chains and high steppes, and partly forming plains and slopes inclining towards the shore line. In some parts, however, the dry land is even lower than the surface of the ocean, forming great basins which only require a flood gate to be somewhere opened to become inundated and converted into inland seas. We must bear in mind that the ground and rock under our feet are not absolutely permanent and solid; long experience and accurate observation have shown that alterations of level are continually taking place; the land rises in one part, while in another it is falling; the surface is blistered into mountain chains; on some coasts the ocean is slowly but surely encroaching on the sinking land, while on other shores the rising land recovers itself from the embraces of the sea. Nothing is stable. The ocean, exposed to the sun's rays and agitated by driving winds, is for ever evaporating, and the moisture thus imparted to the atmosphere is ever distilling down on to the land as rain, or depositing as snow and condensing into glacier on the mountain top. From these causes—from the descent of the glacier,—from the rain drop,

collected first into runlets, which combine to fill the brawling creek,—the creeks in their turn merging into ever-flowing rivers,—there results a continual wearing away of the surface rocks, and a constant bearing down of silt and stony fragments seaward.

All this debris of old rocks, carried away under the waters, becomes in the course of time condensed and re-cemented into new rocks;—mud into shale, quartz grit into sandstone; besides which, the remains of organic life are ever lending material for the general work of renovation,—corals and shells of molluscs, &c., passing into the substance of limestones, and the sodden, rotted vegetation of reeking jungles and forests passing gradually into coal.

Upon these rocks, including the oldest and the newest, rests almost everywhere over the extent of the dry land, a loose, friable covering, very variable in its composition, and known as THE SOIL. This soil, employing the term in its widest sense, may be no more than a very thin layer, or it may be of great depth—it may be a light impalpable powder, such as the tripoli dust (infusorial earth), in which the traveller's horse sinks to his knees, or a dense hard clay,—it may be a bed of broken shells,—it may be only sand, *a sea-beach remote from the sea,*—or mere turf, spongy and treacherous, and almost void of mineral matter,—or it may be a combination of any of these constituents.

Upon this soil, so varied in its characters, man is dependent for food, and for all other vegetable and animal produce, excepting only that portion which he draws from the ocean and its tributaries; and the soil, adapted thoroughly for so great a range of his wants, is endowed with highly remarkable properties. The soil absorbs the sun's heat, and wakens the seed to life. It has the property of holding within its substance a considerable proportion of moisture; it is permeable to atmospheric gases, which it can condense within its porous structure, administering them to the rootlets of plants growing in it. It can also separate soluble salts from their solutions in the meteoric rain-waters, retaining them with a strong hold, but yet administering them as plant food. The organic constituents of a soil undergo a slow and continuous decay, and the gaseous products of that decay are largely fixed in the soil itself for the sustenance of vegetable life. The mineral constituents of a soil are also subject to chemical changes, and certain of them are thus dealt out gradually, and with regularity, for the maintenance of the crop. Of course, you

will understand that these properties are ascribed to soils in a general sense only,—there is, in truth, among so great a variety in the texture and composition of soils a necessary variety in their properties. The arid sand of the desert is the type of sterility; the soft humus of the tropics is often darkened by the vegetation which it supports; its trees are clothed with vegetable parasites, tangled and impenetrable, supporting countless forms of animal life, and overtopping this dense mass rises a loftier tier of vegetable forms, to borrow the language of Humboldt, "a forest above a forest."

An ordinary soil may be sifted, and thus separated into its constituents according to the size of its particles; besides which it may be also washed, and a kind of mechanical analysis effected according to the specific gravities of its several components: the gravel, the sand, the clay, and the humus, or peaty matter, may thus be parted from each other. It would be beyond our limits to inquire concerning the physical properties of soils, but in reference to their chemical composition a few words should be added.

A soil may be dried, so as to ascertain how much moisture it contains. It may be heated to redness, so as to consume its combustible constituents and determine their proportion. These combustible constituents of the soil may be burnt, in such a way as to show how much carbon, hydrogen, nitrogen, and oxygen they contain. Its soluble salts may be washed out, after destroying its organic matter, so as to find their proportions. Its calcareous constituents, its carbonates of lime and magnesia, may be dissolved out by a weak acid; and the soluble salts, the calcareous solution, as well as the siliceous or clayey residue, may each be analyzed, so as to render an account of the original sample treated.

There are certain questions concerning the composition of a soil, requiring a relatively large outlay of time for their determination, but which are to the farmer of relatively small importance; and there are others, also demanding time for gaining correct results, which are of great practical significance. I shall speak of the latter more particularly presently; but in the mean time I would urge the common sense view of the advantage of a selective method of analysis, treating the questions which are vital to the landholder with the greatest nicety, but avoiding the irrational procedure of pushing an analytical inquiry, in sheer obedience to custom, into details for which there is no present application. Speaking in a general sense, the sand in a soil assists its permeability; to

the clay is due in some measure its power of retaining moisture, and in the clay also, especially in that of a ferruginous sort, resides a power of fixation for ammoniacal and other gases. In short, from a careful review of the major components of a soil and its state of aggregation much may be inferred concerning its properties: but there are nicer points, those which concern its power of nourishing a crop, and which usually refer to four or five constituents only. These four or more constituents may be regarded as the cultivator's capital, because when they are present in the soil he can draw on it; he can draw flocks of sheep,—bales of wool,—granaries of wheat,—tuns of wine,—jars of oil,—cargoes of rice, sugar, coffee, indigo, madder,—whatever he wills, weather and climate permitting, as long as these four or five elements are present in the soil, until they are exhausted. The soil, to afford heavy crops, must contain available plant food, compounds of phosphorus, nitrogen, potassium, magnesium, and calcium especially, as I shall endeavour to show in what I am now about to advance concerning the seed and plant.

Let us avoid wasting time in unnecessary definitions: you know quite well that a seed, under favourable conditions of moisture, temperature, &c., germinates, and that it germinates most readily in the dark. It grows into a plant, it will grow to a certain limited extent without nutriment from the soil, but it will not develope into a mature plant unless it be fed. The seed carries a certain amount of nutriment for starting its career, and which is to it what the yolk of the egg is to the embryo chicken; and when the young plant has consumed this little stock of aliment it must thereafter draw its supplies from the soil and from the atmosphere. When the young plant appears above the soil it must have daylight to assist it in taking its food from the atmosphere: deprived of this daylight, it dies. The seed, then, consists of the growing part and a treasury of plant food, and in the growing part or germ proper, resides whatever determines the after-expansion into oak, thistle, or palm. We have never been able to catch a glimpse of anything in the structure of the acorn foreshadowing the branching oak; what we know concerning the relations of the seed to the plant, and concerning the growth of the latter, is of a far less profound nature. I shall proceed to mention a few of the more important facts concerning the composition and nutrition of plants.

We find throughout the whole range of the vegetable

kingdom but few of the chemists' 64 elements. Throughout the whole, carbon is present; it is the essential basis of all organic nature, so much so that organic chemistry is considered as no more and no less than the chemistry of the carbon compounds. Carbon, so essential to structure, is accompanied by nitrogen, which appears to be equally essential for growth. Water, too, is always present in these structures; its components, oxygen and hydrogen, combined, with the carbon and nitrogen, constitute almost wholly the soft tissues of both animal and vegetable structures. Phosphorus, a large constituent of the bony fabric of animals, plays also an important part in the vegetable economy; it is constantly present in the ash of vegetables. So also are calcium, magnesium, potassium, sulphur, and chlorine; and all these, in the right condition for assimilation by the spongioles of the plant roots, must be present in the soil. Silicon also, oxidized and in the form of silica, which forms the polished outer covering of the sugar cane and the glaze of wheaten straw,—the strengthening material of all the tribe of grasses,—must also be present in the soil in the right condition for nourishing these crops. Soils contain silicic acid, as quartz sand and pebbles, in abundance; but quartz is not in the right state,—it has not the proper solubility, and therefore a soil rich in silica may produce wheat so poorly glazed in the straw as to be unable to stand upright. If under such circumstances a soluble silicate be added as a fertilizer to the soil, the evil is remedied, and we obtain thereafter a properly upstanding crop. I shall presently speak more particularly concerning the proper form of plant food.

The public mind has been of late agitated concerning one of the components of animal and vegetable structures, a compound body, which has been named protoplasm (the primary plasm or moulding substance of vegetable and animal growth); of this substance it is my wish to say something, but it is also my earnest wish to avoid entering upon those discussions, and to confine my explanations as closely as possible to that which immediately concerns our subject. Protoplasmic substance in vegetables, as well as animals, is rich in nitrogen; nitrogen is evidently peculiarly fitted for an important *role* in these changes of growth, but the presence of nitrogen, or the presence of the protoplasmic basis, must in neither instance be regarded as the cause of organic development; the nitrogenous

* See the Table of Elements appended to these lectures.

protoplasm is simply capable for growth when under the vital influence, and when favourable external conditions of light, heat, and assimilable food are at hand. The protoplasm, *per se*, is no more the cause of growth than bricks are the cause of houses. Dumas, in his Faraday memorial lecture, has explained the case, clearly, concisely, eloquently:—

"Every organized being is born of a germ; every plant from a seed; every animal from an egg. The physiologist has never seen the birth of a cell excepting by the intervention, or as the produce of a mother cell. The subject of the origin of life remains what it was,—inaccessible, closed. Life is still the continuation of life; its origin is hidden from us, as well as its end. We have never witnessed the beginning of life; we have never seen how it terminates."

You see we know nothing about vitality, our information being strictly confined to the chemical and purely physical relations of these assimilable and constructible materials: let us return to them. The farmer, then, with a soil generally favourable in its broad physical and chemical constitution, must take care that there is sufficient plant food always available for his crop. Let us inquire what this provision entails. This we can do by analyzing our plants. Let us take wheat; a few grains of wheat exposed to a red heat become charcoal; we must supply carbon. While we are charring it, water distils off as a volatile product; we must have the constituents of water,—oxygen, and hydrogen. If we wash the flour of wheat, we separate starch and obtain a residue of gluten; the starch consists of carbon, oxygen, and hydrogen; the elastic gluten is the protoplasmic material, the starch, the inert product of growth. This protoplasmic material is rich in nitrogen, we must therefore have plant food containing nitrogen. The glaze of wheat straw, as I have already explained, is silica; we must therefore supply silica. If we burn our wheat, consuming all the charcoal until we obtain as residue a mere ash, this mineral ash will contain not only phosphoric acid, but also magnesia, lime, and potash; we must therefore supply for our wheat crop, oxygen, hydrogen, carbon, nitrogen, phosphorus, silicon, calcium, magnesium, and potassium; and all these must be in the shape of plant food, "ready change," so to speak, in the soil, transferable through the spongiole of the rootlet into the tide of life,—the circulating sap of the growing vegetable.

Now, from the air, from that above ground, and from the air in the soil, a plant can obtain its carbon. Under the in-

fluence of daylight, the leaves can appropriate the carbon of the atmospheric carbonic acid, liberating the oxygen of that acid, and fixing the carbon as a constituent of all those compounded substances out of which the vegetable structure is built up. The fixed carbon becomes an integral part of the chlorphyll (the green colouring principle of leaves), of the wax, of the essential and fixed vegetable oils, of the cellulose or woody material, of the starch, and, combined with nitrogen as well as oxygen and hydrogen, it becomes the basic material of all protoplasmic substances, of albumin, gluten, casein, and the rest of them.

Certain decaying animal and vegetable substances in the soil furnish a plentiful supply of this carbonic acid to the gases of the soil, and thus to the rootlets of growing plants; but in the atmosphere above ground there is always an abundant supply (on an average 4 parts in 10,000), so that as far as three items of plant food are concerned, the constituents of water, oxygen and hydrogen, besides carbon, the farmer need not trouble himself to provide them.

Nitrogen, abundant in the atmosphere, forming very nearly four-fifths of its bulk, is not assimilable in this form of free nitrogen gas. It is true, however, that besides this large proportion of nitrogen in the uncombinal state in the atmosphere, there are also present, in relatively sparing quantities, certain of its compounds. Ammonia and nitric acid are both present, and these are carried down by rains to the soil, and thus are continually supplying materials essential for the construction of the vegetable architecture.

The ammonia supplied naturally to the soil is all-sufficient for a natural vegetation, but for giving full effect to artificial cultivation, a bounteous supply of assimilable nitrogen,—of compounds of ammonia and those of nitric acid, is imperative. The stimulating effect of guano, and that of old woollen cloth, —that is to say, of albumin, the customary manure for the hop plant,—are examples of the efficacy of nitrogenous manures added to the soil.

But phosphates are required,—assimilable compounds of phosphorus must be available: these cannot be obtained from the atmosphere. Sometimes the virgin soil is rich in them; calcareous constituents may contain a portion of the phosphates of the original shelly or bony matters from which they have originated. Soils derived from the granites and porphyroid rocks are always charged to a greater or less extent with phosphates; indeed, these primary rocks in their schorl,

and minerals of that family, appear to be the original storehouses of the phosphates, which by the degradation of these older rocks are dealt out and distributed into the soil.

The farmer must keep up his supply of potassium compounds, (compounds of sodium cannot be substituted for those of potassium); he must also keep up the supply of calcium and magnesium, as well as sulphuric and silicic acid combinations, and those of chlorine; although some of these, the chlorides and sulphates, for example, are often so plentiful in the original soil as to require no very watchful attention or special provision for an artificial supply.

Whatever he removes in his crops of these several constituents of the soil,—whatever compounds of nitrogen, phosphorus, sulphur, silicon, magnesium, calcium, potassium, he sends to market in these crops, he must replace in the soil, or sooner or later the fertility of his lands will suffer debasement; he must replace them, but that is not all. The materials added to the soil must be in assimilable condition, I desire to lay very particular stress on this point, and will therefore offer a short explanation concerning the mode in which the nutrition of plants takes place.

A plant takes its food from the soil with discrimination; it will not consume whatever is within reach; it is, so to speak, dainty; it will not take up its own proper food unless that food be in a particular condition. The plant food must be in the soluble state, and for quick nutrition this soluble food must present facilities for its solution. The fresh leg-bone of an ox, containing, say, one-third its weight of phosphate of lime, if placed in the soil will not prove a rapidly nutrient source of phosphates; it offers too small a surface to the solvent action of the infiltrating rain-water. If ground to powder before placing it in the soil, the increase of exposed surface will favour the rate of its solution; it will become a quicker manure, although it is obvious that the absolute sustenance contained in it remains the same as that of the unbroken bone. The addition of half its weight of oil of vitriol to the pulverised bone will convert its constituents into a form in which the whole of its phosphoric acid is readily soluble, and easily taken up by the plant; it will prove in this case still quicker in its action than the powdered bone; for although the phosphates, so soluble in this form of the manure, will be re-precipitated as soon as they come in contact with the basic materials of the soil,—with the lime carbonate and iron oxides, for example,—still, in this re-precipitated form they will have

arrived at a state of division very much finer than the merely mechanically pulverized bone, and therefore they will be more easily re-dissolved and taken up.

But it is possible for a substance to be quite soluble without being in the slightest degree assimilable; the shortest explanation of this will be by an example. Let sugar and gum arabic be dissolved together in rain water; if we fold a filter of blotting paper within a funnel, and charge it with our gummy sweet solution, we shall find that the fluid will pass through the open pores of the paper as through a colander, and that the filtered fluid still contains both the gum and sugar. If instead of the porous blotting paper we fasten a disc of paper parchment, or common animal membrane (substances without open pores), on to a wooden hoop, and float this hooped diaphragm on a vessel of pure rain water, when we have poured our solution of sugar and gum on to the upper surface of the hooped membrane we shall find, after a little, that the sugar has passed gradually through the membrane, forming a syrup of sugar only, in the rain water beneath, while the gum remains wholly behind. So it is with the spongiole of the growing plant; the rootlets take nutriment at their extremities only, not through open mouths, not through discernible pores, but selectively, taking up and transposing the food through the substance of the rootlet termination just as in the instance of the paper parchment, and the sugar. Fluids,—gases dissolved in these fluids, and crystallised substances so dissolved, can pass into the substance of the spongiole, but gummy and gluey matters, even when dissolved in water, are debarred by their state from entrance into the plant, and even when constituted of materials required by the plant, must remain in the soil until, changed into the crystallizable as well as soluble state, they can be elected by the rootlet. Here, then, we have another condition which must be observed in the use of nitrogenous manures; for in fresh animal products nearly all the nitrogen-containing substances of muscle, tendon, and bone are in the viscous state, requiring a change before they can become useful: and this change, as it is ordinarily brought about, is a work of time. The rotting process on the dunghill,—the rotting of animal manures by burying them, afterwards digging them up for distribution, are examples pointing to the necessity of a change of state conducive to assimilation.

However much quartz sand there may be in a soil, for cereals silica must be added as a soluble glass; it no doubt

undergoes a gradual change when thus added, passing into the soluble crystallizable condition before it can be taken up. In short, whatever is added as manure must be capable of assuming this assimilable as well as soluble state, or it is added in vain. There is, moreover, another point upon which we may with advantage bestow a few sentences. In the vital processes chemical compounds are frequently broken up, and our plant food should not be added to the soil in forms too stubborn or resistant of these vital operations. The experiments of M. Ville, conducted at Vincennes under Imperial patronage, afford results significant concerning potash compounds added as manure to the soil. He arrives at the view that potassium compounds with strong acids or with chlorine,—sulphate and chloride of potassium,—are of little or no use; while carbonate of potassium, its nitrate, and we might infer also its silicate, are easily split up in the soil, and therefore proper for affording combinations with those weak vegetable acids with which the alkali is found combined in the plant. M. Ville's views, if we receive them in the absolute sense in which he appears to place them, namely,—that the sulphate and the chloride of potassium are useless for vegetable sustenance,—these views are not free from difficulties. Potash is certainly an abundant mineral constituent of seaweeds, their virtue as manure depending in no small degree on their contents of this alkali; yet the potash is drawn by the great family of the marine algæ, not by roots from any soil, but from sea-water, in which the alkali exists in the particular forms M. Ville considers valueless for nutrition. The teachings of M. Ville are probably intended by him as applying in a limited sense and comparative degree only; it is easy to understand that the weaker compounds,—the carbonate, nitrate, and silicate of potassium,—yield up their potash more readily than the sulphate and chloride, and that they are, on the whole, the most eligible; but they are the more expensive compounds, and the question appears worthy of further inquiry.

M. Ville recommends a method of examining a soil so as to find out what kind of manure is required for its improvement; the plan is that of ascertaining by experiment on the small scale what kind of crop it will support. He tells us that ten years of assiduous observation and experiment have led him to recognise that the aliment preferred by cereals is nitrogen; by leguminous plants, potash; by roots, the phosphates. He says, the preferred element, but not the exclusive; for these three substances, in various proportions, are necessary to each

and all; and even lime, which humus renders assimilable, must be added. If, then, the soil is tried experimentally with three different kinds of crops, the failure of any one of them will point out what is wanted; if the roots,—"swedes," or "mangolds," fail, we must add phosphates; if the soil, good in other respects, falls short in wheat crops, nitrogenous manures must be added, and so forth. In short, after taking off any one of these different classes of produce, allowing that the soil before putting in the seed was in good condition, we are to replenish it by adding in each case the "particular" manure, the "dominant ingredient," as M. Ville calls it; potash salts for leguminous plants, for beans, or lucerne; nitrogen compounds for wheat or barley; phosphates for beetroot; adding lime occasionally for the decomposition of the humus.

I leave M. Ville's suggestions in your hands for what they are worth, proceeding in the next place to offer a few suggestions concerning the way in which the farmer should avail himself of the resources of chemistry.

Analyses of the soil may be of great or little use; they may prove a dangerous guide, unless the farmer makes it quite certain that the small quantity analyzed is a precise average, truly representing the constitution of the soil in question.

Analyses are of small use unless performed with extreme accuracy, and so as to determine particularly the proportion of nitrogen compounds, as well as that of all the other plant food constituents,—of potash, of phosphoric acid, and so on.

There are certain questions which even good analyses of the soil will not determine; the material may exist in the soil, and yet be inaccessible to the crop; to divide the precious constituents with accuracy into those in the operative, and those in the inert form, would be, in most cases, a very laborious matter indeed; a good analysis of a soil may show its stamina, its endurance under cultivation, but will not show much concerning its readiness in feeding the plant. On the whole, it seems to my mind that the criterion afforded by M. Ville's experimental method of ascertaining what the soil will grow, and what it is incapable of supporting, especially when supplemented by a good general analysis of the soil, will furnish all that is requisite for forming a correct judgment of what manures to add. That seems to me to be the method most suitable for practice. A good general analysis tells us concerning the general characters of the soil, and by finding out, experimentally, what it will readily grow and what it

refuses to support, we learn what particular form of manure it is in want of, for favouring its immediate fertility.

The analyses of plants, of which there is now so large and reliable an accumulation for reference, affords, perhaps, of all others, the best guide for showing what is to be added in replacement of materials removed by the crops; and this refers not only to vegetable forms, but to sheep and oxen, or whatever stock or produce is removed off the soil. In reference to stock, the voluminous researches of Messrs. Gilbert and Lawes will enable the grower to compute exactly what he is doing; for a flock of a thousand sheep sent to market, he can, from the data of those chemists, compute to a nicety how much nitrogen, phosphoric acid, lime, and each other valuable constituent of the soil they have carried off.

While speaking of the return of the bone phosphates to the soil, I beg to reiterate that whether we remove animal or vegetable substances as our produce, the case is identically the same,—the mineral matter must be restored, or sooner or later sterility supervenes. The constituents of the animal and vegetable kingdoms are alike in kind, differing only in proportions. The protoplasmic material is common to both. There is an animal, as well as a vegetable sugar; oils and fats are common to both; there is even an animal amyliaceous compound, an animal starch. Peligot obtained cellulose, or wood substance, a compound free from nitrogen, as a constituent of the dermal integument of the silkworm. There is an animal indigo, the same as that produced from the Indigofera tinctoria. Albumin, identical with that of the white of egg, is all-present throughout the entire range of vegetable structures; so of casein, and similar compounds. The difference, in short, is one of proportion rather than kind. Vegetables build, animals consume what the vegetable kingdom has constructed. Animals are comparatively rich in nitrogen, because they have proportionally less inoperative matter, less fat stored up in them, than will compare with the cellulose, resin, essential oils, camphors, and other non-nitrogenous products of life, deposited in the tissues of vegetables. In short, all that concerns removal from the soil by the crop, applies with equal force to stock sent to market, and for successful results the farmer must in each case ascertain what he is removing, and what he ought to put back.

It is quite clear that with our exportation of wool, preserved meats, bone-dust, and other animal manures, we are

drawing heavily upon the soil, and that we should in some form or other put back what we take. How long we may go on as we are doing, with impunity, is a question to which it would be difficult to obtain a precise answer; as our domain is so large, we possibly may not feel the result for a very long time: but without doubt it is proper that every one engaged in agricultural or pastoral pursuits should understand the real merits of this question, so as to be enabled to apply it in all its force to his own individual case.

This exportation of manures may be looked at, it is true, from another point of view. Of the exportation of bone manures, particularly, it has been said that the practice is a drain and certain cause of the gradual decadence and impoverishment of the agriculture of the exporting country. Great Britain, so large an importer of these bone phosphates, has been denounced by Liebig as a ravager, rifling the battle-fields of the world for phosphates for her crops, ogre-like, "grinding the bones" of nations "to make her bread." But the view which regards with jealousy this competition of nations for nitrogen, phosphorus, and potassium, as manurial agents, is fast giving way before a commercial system which proves itself to be enterprising rather than competitive. Stores of mineral phosphates,—of coprolite in extensive deposits,—of guano, placed on coral banks in mid-ocean, as though for the benefit of every land, have largely added to the world's resources in this kind of wealth, and a commerce in manures, assumes as legitimate a character as the commerce in breadstuffs. There is no real cause for apprehension that any country will be impoverished by the exportation of manures, unless her people are so apathetic, or so mercenary and shortsighted, as to sacrifice permanent prosperity for a small present gain,—cutting open the goose, so as *not* to get the golden egg. Victoria, at the present time, obtains from her lands a superabundance of produce, in the shape of sheep and oxen; and after disposing of wool, hides, tallow, and flesh, —the latter as preserved meats,—after satisfying all her own wants, she has, left on hand, the bones and a large amount of highly nitrogenous offal and waste, which have been hitherto regarded, in the hygienic sense, as a nuisance, but which are of great value as fertilizers, either for local use, or for shipment. If you will excuse the personal bearing of what I am about to say, I should like to explain that letters-patent have recently been granted me for a method whereby any amount

of this animal refuse and garbage can be converted into merchantable artificial manure, very suitable for either storage or transport. The process is very simple; the organic textures are broken down by oil of vitriol, which acid is afterwards utilized for the formation of soluble biphosphate of lime. The entire carcases of sheep and oxen can be thus treated, or, in whale fishing, the whole fabric of the whale, after separation of the blubber, can be reduced by this method into an article of commerce for which there is an almost unlimited demand. The reason which has induced me to bring this method under your notice is that it promises to afford the means of employing grazing grounds for building up and maintaining land in the arable state: the sheep becomes a collector of phosphates and nitrogen compounds from relatively poor lands, and these phosphates, nitrogen compounds, &c., in the converted carcase, can be applied to bring up soils to any degree of fertility. In this sense, the lands of Victoria become a sustaining power to the sugar and coffee plantations of other climates; we send away this sheep carcase manure, and obtain coffee and sugar in exchange: what we ship is converted into the coffee and sugar brought back. The result is very nearly the same as though we were creating tropical produce out of our own estates. I am inclined to believe that this wide commerce in manures, when well developed, instead of proving a curse, must in the end become of immeasurable advantage, as a means of increasing and distributing food and the necessaries of life to the whole human race.

But it is time that I should conclude what I have to say concerning chemistry applied to agriculture. In this Institution, facilities for a practical acquaintance with agricultural chemistry will be offered to all, and I press upon the attention of those especially who trust to the soil for a livelihood, that it will be greatly to their advantage to accept the overture. There will be many who have not time at their disposal for the work, but they can send the junior branches of their families to acquire in Mr. Cosmo Newbery's classes at least as much chemistry as will enable them to make examinations of soils and manures, and ensure justice being done to the broad acres. It is of vital importance that the farmer buying manures should effect his purchases on a safe footing; and what is now offered will enable him to ascertain for himself how much assimilable nitrogen, how much of phosphorus

compounds, what nitrates, carbonates, soluble silicates, sulphates and chlorides of calcium, magnesium, and potassium these guanos and other composite manures contain, and how much effete matter. The dead weight in a manure, the sand, charcoal, common salt, and clay, although nothing be paid for them, although the phosphates and other valuable compounds present in the manure are collectively worth the price paid down for the whole,—the sand and other such valueless constituents, I say, cost something for carriage of their dead weight before we get our manure on to the farm, and therefore they are worse than valueless; and, therefore, both for the sake of the honest manufacturer of manures and the buyers of them, knowledge for ascertaining the intrinsic value of what is in the market cannot be too widely diffused.

I have yet one final observation to make. In Japan, where the practice is purely empirical, a long experience has nevertheless led to the adoption of a very sound method of culture: the manure is added into the drill along with the seed,—in other words, what is put into the soil in the shape of manure is recovered in the produce without loss of time, and the soil is never impoverished. Fertilizers may be required in order to bring land into a bearing condition, but beyond what is necessary for bringing about this result, the treasuring up of manure in the soil for use in coming years, in fact, any unnecessary delay in realizing the proceeds of our fertilizers, becomes to us a loss of interest on our capital. Soluble biphosphate is speedier than mere bone-dust manure; there was for a long time a great dread of adding highly soluble manures to the soil, under the idea that the rain and drainage would occasion loss by washing them away; but the researches of Way have conclusively proved that the soil fixes these soluble compounds, so that there is, in fact, every inducement to administer the manure either in the dissolved state, or in as fine a state of division as possible, so as to make our available capital return a large interest by turning it over more frequently.

These, then, are some of the more pertinent relations of chemistry to agriculture,—a very slender sketch of the subject, I am aware,—but enough, I trust, for showing that the chemical principles, thus slightly referred to, are the real key to sound and successful agricultural practice. It seems to me that one of the chief wants hitherto experienced by the colony has been that of good agricultural schools. Speaking

out plainly, but of course with deference to the opinions of others, I beg to say that to my mind it is clear that such institutions would confer greater and more lasting benefits than all the medals awarded at agricultural shows. Doubtless, the shows are beneficial, and the prizes an incentive, I should be sorry to undervalue them; but if my views are correct, it would be a national gain to make the establishment of agricultural schools our first aim, contenting ourselves, in future, with artistic bronze medals as prizes: they would confer the full distinction, although not intrinsically so valuable as vessels and medals of silver and gold. We should have, for the same cost, the medals, all the honours which prizes can confer, and the agricultural chemistry to boot.

LECTURE III.

THE CHEMISTRY OF THE SEA.

DELIVERED BY GEORGE FOORD,

ON 13th OCTOBER, 1870.

THIS evening I invite your attention to facts concerning the Chemistry of the Sea. The subject is extensive, it is full of interest, and it concerns us because of its practical bearings upon the chemical arts. It would be rash to promise anything more than a mere outline within the limits of our lecture, but I think I may safely promise to present an outline tolerably accurate in its proportions, if on your part you will consent to give me your best sustained attention during the next eighty or ninety minutes.

To say that the chemistry of the sea is a subject comprehensive and of great interest is to speak in very mild terms,—terms which scarcely convey the truth in its full importance; if you will with confidence accept my view of it, I present this as one of the most sublime of all the subjects open to the inquiry and contemplation of the chemist. The chemistry of the sea has its great geological bearings and mineralogical applications, for the ocean has been largely instrumental in framing the very various stratified rocks, and has played no insignificant part in the formation of the many species of beautiful minerals, with which the fissures or veins in the earth's crust are filled. Besides all this, the sea supports its own vegetable and animal kingdoms, and all the functions, chemical and physical, which the sea is now fulfilling, it has in past ages, from a very remote stage in the earth's history, equally well fulfilled. There is good testimony written within and without almost every sedimentary rock, showing that the sea has during past ages teemed with animal and vegetable forms, some of them similar to those at

present nurtured in the blue depths of the ocean, and others identical with marine life as it exists at this hour. The broad expanse of ocean plays a chief part in maintaining the balance of terrestrial organic nature; from its surface moisture and rain-cloud are continually distilled into the atmosphere, supplying alike the genial refreshing shower, and the humidity stored up in the glacier on the mountain top: by these means the sea is ever preserving the fertility of the land. The ocean is on the one hand a continuous source of pure water to the atmosphere, while on the other hand it is always receiving the sullied outpourings of every land;—rocks ground to powder, and the sewage of the whole globe. The quantity of solid matter carried seaward is immense; directly we begin to measure and compute what is borne down by a single river, our minds are startled with the results. One of the American rivers, the Mississipi, is computed by Lyell, from the results of actual experiment, to deliver annually no less than four thousand million cubic feet of solid matter, of the general character of clay, into the ocean. The quantity thus conveyed into the Bay of Bengal by the Ganges and the Brahmapootra, he has calculated to amount to ten times as much, that is to say, to forty thousand million cubic feet. Yet, with all that is poured into it by all the rivers of the world, with all that has been poured into it in countless ages past, with all that is continually taken from it by evaporation and in other ways, sea-water is pre-eminently a type of purity and freshness, and its peculiar composition is maintained with but little variation all over the globe. The special aptitude of this one fluid, of this pellucid brine, for so many mighty purposes, its fitness *depending on its physical and chemical endowments,* places it as a subject of study and contemplation among those of the very highest human interest.

To review the several functions of sea-water would profitably occupy many lectures; let us on the present occasion content ourselves with a sketch of the chemical composition of sea-water, and with references to a few suggestive facts concerning the functions of these several constituents in nature, or their uses in the arts. Some of the facts which I shall have occasion to mention will be familiar to many of this audience; I shall make no apology for this, excepting by reminding you that obvious facts often form necessary links in a chain of argument or illustration.

Let us commence our inquiries concerning the chemical nature of sea-water by a few simple experiments. Sea-water and pure water, placed side by side in separate vessels, are scarcely to be distinguished by the eye, but it is easy to ascertain a difference by tasting them; and a chemical trial is equally effective in establishing a distinction.

A drop or two of a solution of lunar caustic, unchanged in the pure water, causes an immediate curdy precipitate in the brine; it shows that compounds of chlorine and bromine are present. If a single drop of rain-water be placed on a clean slip of window glass, the water speedily evaporates; it passes away in vapour, leaving scarcely any appreciable residue. If, now, we take a drop of sea-water, and in the same way cause it to evaporate from a strip of clean window glass, we find that it leaves on the glass a solid white crust,—salt to the taste, and composed, in fact, for the most part of common table salt. If we examine the little saline crust thus obtained under a low power of the microscope we discover that this deposit, which to a casual glance might appear insignificant, is composed of a group of crystals, of forms roughly depicted in the diagram before you.* Here, at starting, we have a revelation, obtained from a single drop of sea-water, showing that on evaporation its common salt is rendered up in cubic crystals. Our simple trials with the lunar caustic, and by evaporation on a strip of glass, would detect chlorides in, and obtain crystals from a drop of salt-water, too minute or too weakly saline to affect the palate.

Having ascertained that rain-water is very nearly pure water, and that sea-water contains in solution crystallizable saline matters, let us now push our inquiry one step further. If the salts obtained by evaporating sea-water be redissolved in pure water, we reconstitute a brine, and doing this, we find that certain things invariably take place. The brine, of course, has a weight equal to the sum of the weights of the water and salts from which it is formed; that is quite a necessary consequence, for in all these chemical and physical changes no particle of matter is ever lost. Matter is never lost; and as far as our experimental inquiries have ever reached, matter in all its physical and chemical transformations is never deteriorated or impaired in its properties.

* The diagrams, &c., in illustration of this lecture will be exhibited in the Technological Museum, Melbourne Public Library.

When we liberate carbonic acid from a fragment of limestone, in which it has been pent-up in combination with lime for countless centuries; the carbonic acid is quite precise in its composition, containing exactly six parts of carbon and sixteen parts of oxygen, in twenty-two parts of the gas. The liberated carbonic acid is fully equal to all the functions that carbonic acid has ever fulfilled; though so old that we cannot remotely guess when its elemental carbon and oxygen first came together,—though so old, it is nevertheless as new in every respect, and in every atom, as at its first creation. This applies to all substances and to all chemical changes.

Our brine can be reconstituted, of its original weight, exactly and quite unimpaired in its properties, by the addition of the water which we have evaporated, back again on to the salt left as a residue. But in forming a brine in this way, if we take critical notice of its measurement, we find that the brine, although greater in bulk than the pure water which we have added to the salt, is somewhat less in bulk than the sum of the cubic dimensions of both water and salt. Even with a solid piece of rock-salt, dissolved in pure water, this is so; and it is therefore obvious that during the solution a condensation takes place: so that, unless acquainted experimentally and beforehand with the facts of the case, it would not be possible to predict, from the specific gravity of a natural sea-water, how much salt and how much pure water a given weight of it can yield.

But experiment soon informs us in this matter. An imperial gallon of pure water at 62° Fah. weighs exactly 10 lbs. avoirdupois; in fact, that is what constitutes the gallon: it is the bulk of 10 lbs. of pure water. An imperial gallon of sea water weighs rather more than 10¼ lbs. avoirdupois; or, in other words, its specific gravity is 1·027 to pure water as unity. But a gallon of this sea water, weighing 10¼ lbs., if evaporated, leaves a residue of about 2500 grains, or nearly 6 ozs., of saline matter, of which 1890 grains, or over 4 ozs., is common salt. We obtain in this way two products, pure or nearly pure water, and a salt residuum. Let us, in the first instance, pay a brief attention to the distilled water; to "the pure element," as it is so often called.

Is water really an element? No; it is a compound; but the discovery of its compound nature is of relatively modern date. Of all discoveries within the range of chemical

science, this discovery of the compound nature of water may be characterized as one of the most remarkable. The circumstances of this great discovery are of interest, but we must not dwell upon them now; we pass them over, for it must be confessed that the story is a long one. For our present purpose it will be sufficient to mention that, although the names of James Watt, of Priestley, and of the great and unfortunate French chemist, Lavoisier, are connected with it, matured judgment has, after years of discussion, awarded the merit of priority in the substance of the discovery to our countryman, the great, but eccentric philosopher, the Honourable Charles Cavendish. The announcement that a mixture of hydrogen and oxygen can be burnt into their own weight of water was made by Cavendish in 1784; no more than eighty-six years ago. At the beginning of the present century, two chemists, Messrs. Carlisle and Nicholson, separated water into oxygen and hydrogen gases by the aid of voltaic electricity, and in latter years Grove has effected the same change by heat alone.

There are many ways of demonstrating the composition of water, but the experiment with the voltaic battery is one of the most striking, because by this method we obtain separately both the gases, and can so readily measure and examine them. From one pole of the battery we obtain oxygen gas, from the other pole a bulk of hydrogen gas amounting to twice that of the oxygen; and as hydrogen gas is only one-sixteenth the weight of oxygen gas, it is hence clear that nine parts by weight of water are constituted of eight parts by weight of oxygen and one part by weight of hydrogen; always quite exactly in these proportions. When these gases are mixed in about these proportions and exploded, water is formed; and if, in this case, either gas, the oxygen or the hydrogen, happens to deviate from the proportions mentioned, the excess, whatever it may be, whether of oxygen or hydrogen, remains over and above in the uncombined state.

If a jet of hydrogen is burnt in oxygen, or even in dry air, cooling and condensing the products of combustion, water is produced, and pints of water have been experimentally compounded in this way. But it is possible to invert the form of this experiment; if a jet of oxygen were ignited in an atmosphere of hydrogen, the oxygen would appear to become the combustible; in reality, in the latter case, the flame is merely inverted; this flame is, in fact, no more than

the focus or surface of contact at which the chemical combination takes place, and whence the light and heat resulting from this chemical change emanate. Whether we burn hydrogen in oxygen or oxygen in hydrogen, or mix the two and explode the whole mass instantaneously, in each case water is the product.

As one fifth of the bulk of our atmosphere consists of oxygen, and as a large proportion of the chemical changes witnessed by us consist of the combination of different bodies with this oxygen, and as these combinations are often attended with evolution of light and heat, it is usual to speak of oxygen gas as a supporter of combustion, and in the same sense it is usual to speak of hydrogen and bodies of similar nature as combustibles; but in talking of combustibles and supporters of combustion, we ought to bear in mind that the terms convey a relative, rather than an absolute sense. Combustions are chemical combinations to which, in our particular instance, the oxygen and the hydrogen are both essential, and to which both contribute. It is true that bodies of opposite chemical natures have the greatest aptitude for combination with each other, and that the disposition to combine is strongest in those cases in which the electrical relations are most widely opposed; but the common conception of combustibles and supporters of combustion is one which will not bear strict inquiry.

I will occupy your attention for a moment with an example. You can burn iron in oxygen,—in that case we should consider the iron the combustible, and the oxygen as the supporter of combustion. You can equally well burn sulphur in oxygen, in which case you will consider the sulphur as the combustible, and the oxygen, as in the former instance, the supporter of combustion. Oxygen, in both instances, is a supporter of combustion; iron and sulphur are both combustibles. But in vapour of sulphur you can burn iron, and the sulphur which we just now called a combustible, we must in this third instance consider as the supporter of combustion. You see by this example that the idea of combustibles and supporters of combustion has a relative sense only; all three cases are instances of chemical combination, with resulting evolution of light and heat, and in each of the cases the combining bodies are joint agents in producing the phenomena of combustion.

But concerning the composition of water, there is one interesting fact which should not be passed over unnoticed; it

is a fact of quite recent discovery. For its elucidation I will make reference to the metal mercury, which, like oxygen and hydrogen, classes among the chemist's elements; in other words, mercury is a body which, hitherto, has not been separated into more simple constituents. Mercury, or quicksilver, is the only known simple metal which is fluid at common atmospheric temperatures (say at 62° Fah.). It is true that one other metallic body is known to be a fluid under such conditions, but that body is an alloy of two metals. All the simple metals hitherto known, with the one exception of mercury, are under ordinary circumstances solids, and not fluids. When mercury is combined with oxygen we obtain oxide of mercury; and just in the same way, by combining oxygen with hydrogen we obtain the oxide of hydrogen, or water. Hydrogen combines in an almost endless number of cases as though it were a metal; it displaces metals from their combinations, taking their places, and metals replace it; but as it has been until lately only known when uncombined, in the gaseous state,—on account of its so widely differing from metals in physical properties,—on account of its wanting metallic brilliancy, conductivity, and other properties regarded as characteristic of the metallic state, chemists have not until recently seen sufficient reason for classing it among the metals. Many of the metals may be not only melted, but may be also volatilized and distilled,—zinc is obtained from its ores by distillation, antimony and arsenic may be easily distilled; silver itself has been distilled in the state of invisible vapour, just as water and mercury are distilled: but the vapours of none of these metals are permanently elastic, they condense again into the fluid or solid metal, and in no instance remain as a gas. In mercury we have the solitary instance of a fluid metal; why, then, should not hydrogen afford the one instance of a permanently gaseous metal? Well, recently a step towards proof of the metallic nature of hydrogen, a real step in advance, has been made. Dr. Graham, the late master of the Mint, so recently lost to science, closed his labours with this final triumph, showing us that it is more than probable that hydrogen is positively of a metallic nature. Graham found that metallic palladium, a rare metal belonging to the platinum group, has the remarkable property of condensing into its substance many times its volume,—over nine hundred times its volume of hydrogen gas; and Graham's experimental results and his reasonings upon them go

to show that a real chemical compound of the hydrogen with the palladium is thus formed. The hydrogen, so wonderfully condensed in this combination, is ascertained to possess the physical properties of a metal, and the new compound appears to be a real alloy. The chemical properties of the combined hydrogen are, moreover, exalted in a remarkable degree; for this new form of the element, in metallic combination, will effect chemical decompositions which hydrogen, as a gas, cannot perform. It will, for example, separate metallic mercury and calomel from corrosive sublimate, a decomposition which hydrogen gas is quite incapable of effecting. According to the late Dr. Graham, the new combination is a true alloy of the metal palladium with metallic hydrogen, or with "hydrogenium," as he has named it. In submitting these new facts and views to your notice, I wish to lay stress on one or two points affecting our reliance on them; I wish you to bear in mind that at the time of the discovery Dr. Graham was the most eminent of British chemists; remember that medals have been struck in this new alloy of palladium, and hydrogenium,—one of these medals is in Australia at the present moment; remember also that in the formation of this metallic compound 900 volumes of hydrogen gas are condensed into the substance of and along with one volume of palladium; the hydrogen is not simply condensed or squeezed up into a small space in the pores of the palladium, it is combined throughout, atom for atom, with the latter, and it is transmuted or alchemized into the metallic condition, and permanently retained in alloy with the palladium.

This explanation concerning Graham's "hydrogenium" has point in reference to our subject; for if we accept Graham's deductions from his experiments, we are thereby led to regard water as the fluid rust or oxide of a metal, of which fluid metallic oxide the chief bulk of the ocean is composed.

From these considerations concerning the composition of pure water itself, let us pass on to observations concerning the saline constituents of the sea, concerning the common salt, and its associates.

Sea-water is essentially a mineral water, the saline contents of which consist of chlorides of sodium, magnesium, potassium, and calcium, as well as sulphates of the same bases, together with a number of other substances in smaller proportion, and some in relatively minute quantities.

The total amount of dissolved saline contents in the water

of the ocean, at long distances from land, varies from about 1960 to about 2730 grains per gallon. It is largest near the equator, and smallest near the pole. The greater evaporation of water in tropical regions than in temperate or polar regions, and the unequal influx of fresh water from rivers or as rain, tend to produce local differences which are to a great extent compensated by currents. Forchhammer, who has elaborately investigated the chemistry of sea water, fixes the mean amount of dissolved contents in the water of the ocean at 2408·28 grains per gallon.

The difference in saline contents in different parts of the ocean, occasioned by these local and other influencing circumstances, is accompanied by a corresponding difference in specific gravity.

The specific gravities of sea water from samples taken from different parts of the globe are quoted by Gustav Bischof:—

	Specific gravity.
From the Atlantic Ocean, according to Von Horner ...	1·02875
,, Antarctic Ocean	1·02692
Both oceans, the Chinese Sea included.	
In the Northern Hemisphere	1·02795
,, Southern Hemisphere	1·02765
,, Northern Hemisphere, according to J. Davy......	1·02801
,, Southern Hemisphere, ,, ,, ...	1·02712
Atlantic, Pacific, and German Oceans, according to Von Bibra	1·0244 to 1·0287
In Southern Hemisphere, according to Jackson,	1·026 to 1·0275
Atlantic, Pacific, Bay of Bengal, and Indian Oceans, according to Darondeau	1·02545 to 1·02577*

This table of the specific gravities of the salt water at different parts of the ocean will convey a good idea on this point: if the first two figures, the 1.0, be regarded as whole numbers, representing 10 pounds, the weight of a gallon of pure water, then the remaining figures, considered still as decimals, will show in fractions of a pound the excess weight due to the saline contents.

Where these differences of specific gravity and proportion of saline contents occur, the saline contents themselves are remarkably constant in their proportions with each other. Thus, taking the chlorine from among the constituents, Forchhammer found the maximum, minimum, and mean

* In the work quoted—*Chemical and Physical Geography*, by Gustav Bischof, translated and published for the Cavendish Society, London, 1853—the reader will find much solid information on this and kindred subjects.

proportions of the other chief constituents to be as given in this table:—

Sulphuric Acid and Oxygen of the base SO_4.	Magnesium.	Calcium.	Total saline contents.	Chlorine.
Maximum... 14·51	6·768	2·257	181·4	100
Mean......... 14·26	6·642	2·114	181·1	100
Minimum... 13·98	6·570	2·050	180·6	100*

Let us obtain an idea of the amount of these several materials by reference to one of Von Bibra's analyses; let us take an analysis of his of water from the Atlantic, lat. 41° 18′ N., and long. 36° 28′ W. Taking its specific gravity at 1·0287, then one imperial gallon will weigh 72,009 grains (or 10 lbs. 4 ounces 259 grains); 70,000 grains would be the weight of its bulk of water. I propose to present these several proportions to you, as well as I am able, in a visible form; for that mode of conveying information is by far the readiest. The imperial gallon contains 277·274 cubic inches, which would be equalled by a sphere of a little over 8 inches diameter (8·0935 inches diam.).

Then this gallon of sea-water, this sphere of brine of a little over 8 inches diameter, weighs 2009 grains heavier than its bulk of fresh water, and it contains in 100 parts by weight 3·84 parts of salt and 96·16 parts of pure water. According to this, our gallon of sea-water taken from the Atlantic will contain in all 2765 grains of salt and 69,244 grains of pure water; (9 lbs. 14 ounces 119 grains of water, and 6 ounces 140 grains of salt). It contains, therefore, nearly an ounce and three-quarters less water than a gallon of pure distilled water. Here are the salts, and this is the bulk of water displaced by their solution; 2765 grains of salt displacing 616 grains of water from the gallon.

These salts from one gallon of water, calculated according to this analysis of Von Bibra's, afford the following constituents:—

	Grains.
The common salt, or chloride of sodium, forming over three quarters of the whole	2126·00
Of chloride of magnesium there is	222·58
Of chloride of potassium	92·07
Of bromide of sodium	35·94
Of sulphate of lime, or gypsum	136·59
Of sulphate of magnesia (epsom salts)	151·76
	2764·94

* From *Watt's Dictionary of Chemistry*. Longman, London, 1868. Vol. V., p. 1019.

To assist our conception of this table, I have weighed out the proper quantities of each of the above substances; here we have a dissected view of the saline and other constituents of a gallon of sea-water.* We have the water and the pure common salt,—the chloride of magnesium,—the chloride of potassium,—the epsom salts or sulphate of magnesia, dried so as to be free from water of crystallisation,—the gypsum or sulphate of lime, and the bromide of sodium. You see that although the common salt forms so large a proportion of the solid constituents, the others, the epsom salts, &c., are not by any means insignificant in their relative amounts.

But these saline constituents of sea-water are every one of them compounded of yet more simple parts; just as oxygen gas forms oxides with the metals, so chlorine gas forms chlorides; and besides the chlorides of sodium, potassium, &c., we have in sea-water still more complex combinations, namely sulphates, in which sulphuric acid is combined with the oxide of a metal.

Let us bestow a passing attention on these combinations of the elementary substances of which these saline compounds are made up. When metallic sodium is heated and plunged into chlorine gas it burns fitfully, combining with a very large bulk of chlorine. The metal and the gas disappear during this combustion; the whole of the chlorine disappears *if there is present enough sodium for its absorption:* these constituents, the sodium and the chlorine disappear, and common salt is the product. I shall refer more particularly to this combination in a few minutes.

That sulphur will combine with oxygen is shown by igniting sulphur and plunging it into a jar of the gas. Under favourable conditions of combustion (those insured on the manufacturing scale by the oil of vitriol maker), the sulphurous acid produced by this combustion receives a further dose of oxygen into combination, passing to the state of sulphuric acid; and this sulphuric acid may be readily combined with metallic oxides so as to form salts, so as to form sulphates, such as the sulphate of magnesia and the sulphate of lime, of sea-water.

I have calculated, and endeavoured to express by diagram and model, the amounts of the elementary substances forming the pure water and the salts in our one gallon of sea-water.

* The series representing the constitution of sea-water will be exhibited in the Technological Museum.

First, the pure water itself, nearly ten pounds in weight, can be resolved into something over 103 cubic feet of oxygen, which would fill a sphere of a little over 70 inches diameter; and of the gaseous metal, hydrogen, something more than 207 cubic feet, occupying a spherical space of nearly 88¼ inches diameter.

Besides the oxygen of the water, there is the oxygen of the sulphates, something more than 145 grains; this is equal to 423⅓ cubic inches, a bulk equal to a spherical capacity of a shade over nine and three-tenths inches diameter.

Now we come to the common salt constituents, the chlorine, and the sodium, you observe that there is chlorine combined with magnesium and potassium; the whole chlorine in our gallon when separated as gas will equal quite 1500 grains; in bulk it will occupy 1959·8 cubic inches—over seven times the bulk of our gallon of sea-water,—more than a cubic foot of this orange-coloured gas in a gallon of salt-water. See what this means; it means that if the chlorine no longer kept its appointed place in combination with the sodium magnesium and potassium, the ocean, covering three-quarters of the earth's surface, and let us say, of an average depth of four miles, would give up over seven times its bulk of this corrosive gas, under whose influence all life, vegetable and animal, would immediately cease. The chlorine of our gallon of water would fill a sphere of a little over fifteen-and-a-half inches diameter.

Now we come to a group of metals, which in their free solid state would occupy dimensions much less than those elementary constituents already considered. The sodium, weighing nearly 1844·1 grains, and lighter than water, would occupy a sphere of this size,—one inch and eighty-seven hundredths of an inch diameter.

The potassium, another alkali metal, also lighter than water, exists in the gallon to the extent of over 48 grains; it would form a sphere of almost exactly three-quarters of an inch diameter.

Then, of the magnesium, which burns with so brilliant a light, a kind of pocket daylight, we have in every gallon of sea water about 86¼ grains; it is 1¾ times as heavy as its own bulk of water, and this quantity, equivalent to a gallon of sea water, would have a spherical dimension of a little over seven-tenths of an inch diameter.

The calcium, the metallic basis of lime, is in yet smaller amount; a gallon of sea water contains a little over 40 grains

of it; it is a little over $1\frac{1}{2}$ times as heavy as water; it would form a sphere of something under six-tenths of an inch diameter. Calcium is one of the coloured metals, and is of a pale yellow tint.

Two other constituents remain; the bromine of the bromides, and the sulphur of the sulphates; the latter exists in the more considerable proportion. One gallon of sea water contains in its sulphates over $72\frac{1}{2}$ grains of sulphur; if we compute it at the density of sulphur in the crystalline state, it will occupy a space of nearly fifteen-hundredths of a cubic inch, and its spherical dimensions will be a little over sixty-five hundredths of an inch diameter.

The bromine remains for consideration. Bromine is allied to chlorine, but at common temperatures it is a volatile fluid instead of a gas,—a deep red, almost black fluid; according to our analysis this gallon of sea water contains nearly 28 grains of bromine, its specific gravity is something under three times the weight of water, it would fill a little glass globe of a shade over four-tenths of an inch diameter; there would be a pretty large pill of liquid bromine.

These, then, are the constituents of our gallon of sea water from the Atlantic, computed according to Von Bibra's analysis; but are these all the constituents? The truth is that these are the bodies existing in large proportion, and that there are others existing in minute proportion, constantly present, but which owing to their minute proportions do not sensibly affect the figures already given. These metals and non-metallic elements, the major constituents of sea water, have their lesser satellites, attending them through their various chemical changes; and in sea-water these satellites are present just as they are generally present throughout the domain of the mineral kingdom.

By spectrum analysis and other methods of research certain of these bodies have been discovered in sea-water; and where experiment has failed to discover certain of them in the sea-water itself, a no less certain proof of their existence in the sea has been arrived at by analysis of marine algæ or of molluscs, or other animals living in, or nourished by, the ocean. We must content ourselves with merely glancing at this most interesting subject.

Before doing so, however, I may mention that, besides the mineral salts, sea-water contains also dissolved gases. Agitated by storms and lashed into foam at its surface, the sea-water is thus brought into intimate contact with

the atmospheric gases; this favours the solution of small proportions of free nitrogen and of oxygen gases, subservient to the respiration of the host of creatures furnished with gills and living in the deep. There is, besides, free carbonic acid from various sources, and other gases in yet lesser proportion. Besides the gases, there are also, as I have said, very minute proportions of mineral matter, attached by a chemical cousinship to the larger saline constituents, attached to their systems, so to speak, as satellites are to planets, and no doubt forming important integers of the complete fabric.

We are not for a moment to suppose that because these minor constituents are in small proportions they fulfil no proper office. From the mechanism of a common watch we can remove no petty link of its chain,—no pallet or pinion, however small its dimensions, without disorganising the whole,—without stopping the daily rounds of the hands, without spoiling that beautiful symmetry upon the complete integrity of which the due performance of its work depends. Is the great ocean less exact in its movements? in its rhythmic waves and pulsing tides, or in its chemical performances? Very little attention is required for ascertaining that the great ocean, viewed as one vast machinery, acts and circulates with a precision altogether unattainable by chronometer or other product of mere human effort; and even where we fail to connect the presence of the minor constituents of sea-water, of which I am now about to speak, with some particular function, we may very safely take what we know concerning the offices of the other constituents as evidence that these bodies, present in what is sometimes spoken of as minute traces, are not only contributive in an outside sense, but that they are essential, integral parts of a perfect whole. I think we may very safely take the instance of the presence of minute proportions of soluble silica in sea-water, and its obvious natural function in forming the framework or skeletons of minute forms of organic life, as conclusive evidence of the special uses of all of these minor sea-water constituents.

There are, as I have stated, two modes of ascertaining the presence of these minute constituents in sea-water; we may seek them in the water itself, or we may look for them in the plants and animals nourished in the bed of the ocean. When we consider that every kind of soluble constituent finds its way into the rivers, and that the rivers are pouring down into the sea, we are led to expect the presence of a

great variety of soluble substances in sea-water. When we reflect on the wave action, lashing the coast lines of the land, grinding down the rocks to powder and dissolving whatever is soluble, we are naturally led to expect the presence of many mineral constituents of these degraded rocks in sea-water; and a critical examination, well directed and sustained, is often rewarded with a discovery of the kind.

I wish you to understand of these minor constituents, that though their proportions appear minute, their amounts in the aggregate are enormous. Suppose a constituent forming no more than one twenty-millionth of the weight of sea-water,—in one gallon there will be thirty-six ten-thousandths of a grain of that substance; for simplicity, say there are four thousandths of a grain in a gallon. An excellent analyst may detect this small constituent, separate it, and weigh it, for four thousandths of a grain is a tangible quantity. But let us ask how much of this constituent would exist in the whole ocean, so as to be present at the rate of four thousandths of a grain in each gallon of sea-water. At the first aspect of the case the mind regards this four thousandths of a grain in the gallon as an exceedingly minute, almost insignificant proportion; but when we reflect and calculate concerning this small constituent,—when we endeavour to realise a conception of the total amount in the whole ocean which it represents,—we find our feeble intellects baffled by its enormous amount; what at a first glance seemed insignificant, appears in its totality of overwhelming magnitude. Taking the weight of the sea at two-and-a-half trillions of tons, we can easily calculate that no less a quantity than one hundred and twenty-five thousand million tons of this minor constituent exist in solution in the ocean, and which is represented by our four thousandths of a grain obtained from the gallon.

Let us turn to this table, in which all the minor elements, directly or indirectly proved to exist in oceanic water, are arranged. I wish there were time to dwell on this part of our subject, for to my mind it appears to be one of very great interest indeed. I fear that we can do little more than glance down the column. You see iodine makes itself known as a constituent of sea-water by its existence in the ashes of fuci or seaweeds,—the source of the iodine of commerce; these plants collecting it, and treasuring it up from sea-water.

Fluorine is directly and indirectly proved to be a minor

constituent of sea-water; it has been detected in corals and in the boiler incrustations of transatlantic steamers.

Phosphorus, as phosphoric acid, is a never failing part of sea-water; it contributes to the formation of the phosphate of lime of the bony fabric of all fishes and cetacea, from the smallest of them up to the massive skeleton of the great whale.

Carbon, in combination as free carbonic acid, is ever ready to take up small proportions of limestone into solution as bicarbonate of lime. Silicon, too, as the base of quartz, is always there. In some of the lower forms of life,—in sponges, and in the countless infusorial forms,—the solid skeleton is not of phosphate of lime, or of a mixture of that salt with lime carbonate, but really of flint or opaline silica; this material, too brittle for the skeleton of larger forms, combines lightness with strength in these lower organizations, in which, owing to their minute size and small surfaces, the brittleness of the material, as manifested in larger masses, has not the slightest significance.

Boron, a body allied to carbon, and a constituent of the boracic acid of commercial borax, has been in several ways proved a constituent of sea-water. It has been proved by indirect means by Forchhammer in marine plants,—in zostera marina, and in the common fucus vesiculosus. Its presence in sea-water has been inferred, also, from remarkable facts pertaining to the rock salt deposits at Stassfurt, near the Hartz Mountains, in Prussia. Rock salt shows every evidence of having originated from the saline constituents of sea-water. But do not understand me as asserting that the exact mode of formation of rock salt deposits, from sea-water, has been satisfactorily made out. If we compare rock salt with the saline matter obtained by evaporating sea-water, we find the rock salt, as it occurs in nature, to be a remarkably pure form of chloride of sodium, often containing less than one per cent. of foreign saline matters. At Stassfurt there has been discovered, above the rock salt itself, deposits of other saline minerals, double chlorides of potassium and magnesium, and other combinations of similar character; and these new minerals are obviously the complement of the rock salt upon which they rest. Adding the one to the other, they collectively represent all the saline constituents of sea-water; the chloride of potassium, as well as the chloride of sodium, the magnesium salts, the gypsum, and, in short, all the sea-

water constituents. Now among these interesting Stassfurt minerals is one called "Stassfurtite," which mostly consists of borate of magnesia; and with other evidence, the occurrence of this mineral in these deposits is taken as a part proof of the existence of boron in sea-water. There is, however, a direct proof to the same effect; Professor Forchhammer, by an elaborate investigation of water taken from the Sound at Copenhagen, has obtained conclusive evidence of the presence of boracic acid in it.

But substances yet more precious, in a commercial sense, exist in sea-water. Malaguti, Durocher, and Sarzeaud obtained small quantities of metallic silver from the ashes of sea-weeds, and even by operating on large bulks of sea-water itself. Forchammer has in the same way obtained silver from coral, so that there is really no doubt of the ocean being one vast liquid silver mine. Frederick Field, an old and valued friend of the present speaker, obtained another kind of proof of the existence of silver in sea-water; when in Chili, he observed that the ship's coppering, or Muntz' metal, contained, after exposure to the action of the sea, more silver than the trace existing in the metal when first put on. In a ship there are certain cabin and other fittings in which the same metal as the outer sheathing is employed; these fittings are made at the same time as the coppering of the ship, but these fittings are not exposed to the direct action of the sea-water. Mr. Field found that the sheathing showed on assay a higher contents of silver than the same metal employed in the ship's cabins; and that in old ships the sheathing was richer than in new ships; and that metal which had been re-manufactured had treasured up silver, acquired from the ocean by this galvanic precipitation. Malaguti and Durocher obtained silver at the rate of one part of the metal for one hundred million parts of sea-water; which is equal to nearly ninety-six thousand pounds of silver per cubic mile of salt water, or, say, about twenty-five thousand million tons of silver for the whole ocean.

By methods, direct or indirect, copper, lead, zinc, cobalt, iron, manganese, aluminium, strontium, barium, and lithium, have been detected, and it is possible, nay, it is highly probable, that there is a lower platform of other substances beneath these minor constituents, and which the chemist's art has not yet reached, but which, if they exist there, are certainly not there in vain. Two new metals—rubidium and caesium—have been discovered by Professor Bunsen, of

Heidelberg, in the waters of a salt spring. Bunsen discovered these substances by the aid of that new tool of the chemist and physicist,—the method of spectrum analysis. For the separation of very small samples of these new substances, he operated on enormous bulks of the brine, calling to his aid the resources of the furnaces of a large chemical manufactory for their evaporation; and afterwards selecting out by chemical means the desired salts of the new metals. It is highly probable that caesium and rubidium, which exist in these salt springs, exist also in the waters of the ocean; although possibly in such small proportions as to require operations on a very large scale indeed for their detection.

Let us now pass on to a few concluding remarks concerning the uses to which the human race devote certain of these sea salt compounds. The common salt, the most plentiful, is also the most immediately applicable to man's wants. It is the only mineral substance consumed by man as an indispensable article of food; a tax on salt rigidly enforced is known to reach with certainty every individual of the community to which it applies. It is not in any sense a matter of choice whether we shall eat salt, or whether we will dispense with it; the system cries out for it, and if we do not get it in its pure and separate state, or in some form admixed with our food, the vital fluids suffer derangement, and disease and all kinds of consequent miseries are experienced. The pressing necessity for common salt as an article of food is shown by the extent to which it is possible to tax it. In England, duties on salt were imposed in the reign of William III.; in 1798 they amounted to five shillings per bushel, but were subsequently increased to fifteen shillings per bushel, or about thirty times the value of the salt. You may go on increasing the tax, and the people will either pay it, or evade it by smuggling or illicit manufacture; but in any case they cannot do without the salt. The Gabelle, or code of salt laws of France, annually sent from four thousand to five thousand persons to prison or the galleys for offences against them, and the burden became at last so oppressive as to have had no inconsiderable share in bringing about the Revolution.

But salt has also the valuable property of preserving animal food; although it is probable that improved methods of preserving flesh food without the use of salt will before long effect great changes in victualling the navies of the world, and in the transport of animal food from one continent, where it is superabundant, to another, where it is

scarce; still we must not lose sight of the inestimable benefit to the human race which this simple and effective method of preserving food, by salting, has been in past times. We must regard it as a powerful instrument for averting famine on the one hand, and for promoting commerce on the other. Very little reflection will convince us that it is a wonderful thing that the sea, yielding shoals of fish, should also prove a treasury of salt for curing them.

But the salts of the sea are also a grand store of chemical substances, all important in the arts. It is not saying too much to assert that sea-water is the starting point of the modern chemical manufactures. Our little sphere of sulphur,—the sulphur contained in a gallon of sea-water, is equal to a little over half-an-ounce of vitriol, and although we do not manufacture oil of vitriol directly from the sulphates of sea-water, yet the grand primary source of the sulphur which we annually burn into so great a wealth of oil of vitriol appears to be these very sulphates of sea-water. For the manufacture of our oil of vitriol we must have either sulphur or pyrites (the latter being a compound of sulphur and iron); and there are many facts leading to the conclusion that native sulphur, found so frequently associated with gypsum and common salt, and the pyrites in mineral veins have both derived their sulphur from the waters of the ocean. Again, the sodium of the common salt is the basis of all the soda of commerce, and the soap and glass manufactures are supported almost entirely on the basis of a cheap and abundant supply of the alkali obtained from sea salt.

We saw, too, that common salt contains not only this silver-white metallic sodium, but also this yellow gas chlorine; at the present day all our bleaching of woven fabrics, of paper pulps, and of all kinds of fibres and textures, is done with this chlorine; and all the spirits of salts, all the bleaching powder, all the chlorine gas, used throughout the manufacturing world derive the chlorine itself from common salt, directly or indirectly a product of sea-water. Oil of vitriol, soda, and bleaching powder are, then, the basic chemicals,—the tripod foundational to a large and most important class of those manufactures in which, particularly, chemical principles are involved. The three constitute one of the sources of Britain's wealth; they are implements of the Anglo-Saxon modern civilization.

Calling your attention to the importance of oil of vitriol, soda, and bleaching powder, I wish to do so without in any sense underrating the value of other materials, the objects

or means of chemical manufacture. Other materials are confessedly quite indispensable, fuel, of course, is all important, and for metallurgical operations you must have the metallic ores; but what I wish to point out is that sea-water is a repository of sulphur, sodium, and chlorine, and that these three elements are foundational to a very wide range indeed of modern chemical industries.

All the sea-water compounds, the several chlorides and sulphates, have their particular economic applications; and besides this, the elements composing these bodies, the sodium, potassium, magnesium, calcium, and bromine have, or will soon have, their respective useful applications. Speaking of them collectively, we may say that they are materials coming into use, and that at this early date of their introduction we cannot foresee to what extent they will play parts in the manufactures of the future. Magnesium is at present used as a source of intense light; sodium is used in the manufacture of aluminium and metals of that class; it is also employed in gold extraction. Bromine is of use in photography and medicine. Calcium, as a separate metal, is still a chemical rarity; and metallic potassium, although we are quite familiar with it, has not yet done as active service as the more facile sodium.

Respecting the compounds of potassium, I wish, in conclusion, to speak somewhat more particularly: you remember what was said concerning the necessity of common salt in the animal economy; compounds of potassium are in a similar way a special requirement of the vegetable kingdom, and not only do we find potash in the ashes of plants (its name, in fact, refers to this source of the alkali), but we find potash in the soils, and whenever a soil is prolific, potash is always found as one of its minor constituents, in what may be called relatively abundant proportion. When a soil has been robbed of its potash by continued cropping, the farmer finds it necessary to add this alkali, in one form or another, as manure. The felspar of granite contains 12 or 13 per cent. of potash; this alkali is a constituent of porphyries, gneiss, granites, and rocks of that class, and the constant weathering and degradation of mountain chains, by rendering a supply of potash, as well as other valuable materials, has contributed to the fertility of the open country and plains between the dividing range and the coast line.

But this supply to the soil is not in every case sufficient; one of the tendencies of continuous forced cultivation is to rob the soil of its potash, and, to avoid sterility, this alkali

must be replaced, often from some auxiliary source. This creates a demand in commerce for potash salts; there are, in fact, two great channels of consumption for these salts,—there is the demand for nitrate of potash, or saltpetre, for gunpowder, and the farmer continually demands potash for his crops. The combined demand is exorbitant, and the supply has occasionally fallen short of it. You will see, in reference to the employment of this article of commerce, that the claims of war are antagonistic to those of more peaceful pursuits, and how a poll tax payable to the State in nitre, as it has existed in Sweden, compels the farmer to bestow the potash-yielding materials at his command, not on the manure-heap for the benefit of his tillage, but on the nitre-bed, so as to furnish his Government with gunpowder.

You will see from this explanation the great value to agriculture of the discovery of the Stassfurt deposits, so rich in potash salts. To come upon so unexpected and bountiful a supply of available potash salts is something very much like a new lease to agricultural pursuits, in all those cases in which the soil is breaking down for want of the one valued constituent, potash. Tobacco is particularly rich in this alkali; it soon robs and ruins the richest soils, so that large tracts have been abandoned altogether after impoverishment by the cultivation of the fragrant narcotic weed. The potash salts of Stassfurt will in future enable the cultivator to get over difficulties of this nature, and you will observe that these Stassfurt potash salts are obviously derivatives of the great ocean.

When the first Napoleon had a large outlet for gunpowder,—when his demand was greater than the available supply,—when, to speak in vulgar parlance, he was "hard up" for saltpetre, he set his chemists to work to find a source of the coveted material. I believe it was found that in exhuming the remains of the departed,—removing the bones of some of the ancestry of France to catacombs, a good opportunity of lixiviating the soil of former burying places, and of separating the contained nitre, would be obtained. It is stated that the nitre was obtained in that way; of course the nitric acid of the nitre was wanted as well as its potash, but potash in addition to soda is a necessary constituent of the human frame; the animal juices, the blood cells particularly, are rich in it; and therefore, if we are to give credence to the account, it amounts to this, namely, that the dead, their physical remains, their ashes in the form of villainous saltpetre, under

the sway of Napoleon I. became arbiters for settling the quarrels of the living.

It was open to Napoleon to obtain any amount of potash, convertible into nitre, from the ocean itself; but, possibly, at that date this source of the alkali was not contemplated. At the present day, in the South of France, M. Balard carries on operations in which sea-water is treated with the object of obtaining not alone the common salt, but mainly the salts of potash and magnesia. The works are at Marseilles, where the climate is warm and favourable to his operations. The sea-water is allowed to evaporate spontaneously until it has a specific gravity of 1·24, and during this evaporation it deposits about four-fifths of its common salt. It is then mixed with one tenth its volume of water, and artificially cooled to the zero of Fahrenheit's scale (this cooling is effected by Carré's continuous freezing process, in which liquified ammoniacal gas is the cold-producer). Being cooled, the saline solution deposits a quantity of sulphate of soda, resulting from the decomposition of part of the remaining chloride of sodium by the sulphate of magnesia. The mother liquor is evaporated down till its specific gravity is 1·33, a fresh quantity of chloride of sodium being deposited during this evaporation. When the liquid cools it deposits a double salt, composed of chloride of potassium and chloride of magnesium, from which the latter may be extracted by washing with a very little water, leaving the chloride of potassium fit for the market. The process of M. Balard is instructive, as illustrating the influence exerted upon the arrangement of the various acids and bases in a saline solution, by the temperature to which the solution is exposed; the general rule being that a salt is formed which is insoluble in the liquid at that particular temperature.*

So you see that we have in our sea-water, besides the useful chemicals already enumerated, also an inexhaustible supply of potash, available, as we may choose, for either agriculture or warfare.

In the remarks offered I have endeavoured to present a popular sketch, showing the composition of sea-water, and I have glanced at some of the economic applications of its constituents. I have endeavoured to render my explanations in simple unadorned language, leaving much that may be deduced from the facts to spring up spontaneously in your minds. I have felt this treatment to be the best and safest,

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* *Bloxham's Chemistry*, Churchill, London, 1867, page 263.

for a reason which I will now, in conclusion, endeavour to convey. We know that some admirable things concerning the sea have been written by the poets, but even with poets, —with those endowed in the highest degree, this theme is possibly one of the most taxing and hazardous. With ourselves, who are not poets, it is obviously dangerous to attempt lofty language while speaking of so truly sublime a subject as the ocean. When any two of us happen to be seated together on the sea beach,—under a blue sky, let me say,—watching the waves as they come rolling in, when no breakers are dashing into surf, when the booming utterance of the waves is hushed and there is every opportunity for conversation, if we will,—I think I am correct in stating that under such circumstances we are far more inclined to fall into meditation than to break out into words. A train of unexpressed thoughts will flow through the mind of each observer, or should there be any sustained conversation, springing out of what is there, the sea itself will not often be the topic, the "ever sounding sea" will be the chorus, rather than the topic. To intelligent minds the contemplation of the face of the ocean,—the changeful expanse of waters, is felt to be a great privilege, and with intelligent persons, with that absorbing object in view, it is natural to think much,—to ponder,—but to give comparatively little utterance in words. There are thoughts which words cannot adequately express,—for them the requisite terms have not been coined. Speech is often less eloquent than gesture; even a glance may convey a deep meaning, concerning which, excepting for this mode of communication, we should be otherwise mute. Who has ever verbally described a sunset in terms equivalent to those in which the great Turner has painted sunsets? what word-painting could depict the endless variety of sunsets as Turner has depicted them? We may make mention of the gloom of a dense forest; but who can command language which will adequately express what is felt under that influence, or render into words our musings on the sight of an everlasting waterfall? The ocean in its chemical relations is not less beautiful or pregnant with deep meaning than in its other aspects, and therefore, with your permission, we will rely on the eloquent meaning which underlies our facts. The facts shall speak for themselves, making their own suggestions in their own convincing way. Adopting this course, I will dispense with peroration, and conclude by thanking you for your patient attention.

LECTURE IV.

THE CHEMISTRY OF THE ATMOSPHERE.

DELIVERED BY GEORGE FOORD,

ON 27th OCTOBER, 1870.

IN lectures on Applied Chemistry it becomes necessary to make frequent reference to the gases of the earth's atmosphere—for these gases are known to play important parts in the combustion of ordinary fuel, and in many other operations with which the manufacturer is concerned. As the short series of lectures now in course of delivery, on Thursday evenings, is intended as a popular introduction to more methodical and detailed teaching, it has been thought admissible and desirable that a concise and general description of the gases of the earth's atmosphere be included in the series.

According to this view, the subject chosen for this evening's lecture is "The Chemistry of the Atmosphere,"—in other words, the chemistry of that spherical gaseous ocean which envelopes the whole globe, and which is external to the sea,—the medium in which we exist, just as forms of aquatic life exist in the watery deep.

During the earth's daily rotation on its axis, our atmosphere revolves with it, and as the earth travels round the sun, the atmosphere accompanies it: it is, indeed, an integral part of the earth,—that is to say, its outer layer.

The exact height of the atmosphere from the sea line to its extreme outer boundary is not at the present date precisely ascertained; but if we take Dr. Wollaston's computation at 50 miles, which will certainly include nearly the whole of its ponderable material, it will appear that it is of but limited extent beyond the earth's solid surface;—of limited extent as compared with the diameter of the earth itself.

Let us endeavour to gain a just idea of this proportion. Let a globe of 16 feet diameter represent our earth, on a

scale of 2 feet to 1000 miles. I have measured off a radius of 8 feet for drawing a portion of such a globe; to represent the 50 miles,—the height of our atmosphere,—I must add one inch and two-tenths to our 8 feet radius; when the exterior curve which we thus obtain will make it evident to our senses that this atmospheric mantle of the earth is no more than a thin outer covering. It will assist our conception of this, to mention that on a globe representing the earth on the scale chosen, the deepest mine would be represented by half the thickness of a very thin visiting card; the highest mountain we may also represent by a protuberance of a little over one-eighth of an inch; the greatest depth of the ocean, probably, by a depression of equal amount.

In speaking of the chemistry of the atmosphere it is not easy to avoid reference to its physical properties; but as the time at our command is short, what I have to say concerning the physics of the atmosphere will be compressed into dimensions as compact as possible. The physics of the atmosphere is certainly a large and interesting subject, courting our attention by its attractive interest; but in what I have now to present, it will be my aim to make reference to these physical properties only as far as the doing so will assist our conception of the chemistry of the subject.

The atmosphere, in common with all other forms of matters, gravitates, pressing upon the surface of land and ocean with a pressure of about 15 lbs. upon every square inch of the earth's surface. The atmosphere presses upon the surface of each of our bodies with an aggregate pressure of no less than eleven tons; but as the fluids of our bodies are sensibly incompressible, and because our lungs and tissues are permeated by air of the same pressure as that without, and because the pressure distributes itself equally in all directions,—upwards and downwards, and laterally,—because the air is mobile and elastic,—we are insensible to this mighty pressure under which we constantly live. Many of our physiological experiences depend on the pervading presence of air; but finding these in the cradle, mankind for ages accepted them as a matter of course, with little inquiry, from the cradle to the grave.

But this ignorance concerning the physics and chemistry of the atmosphere was not always to endure. Inquiries concerning the materiality and weight of the atmosphere took an experimental form at the close of the life of the great philosopher Galileo. It will fix the date to state that

our Lord Bacon was born in 1561, and that Galileo was Bacon's junior by three years. Great discoveries are not unfrequently referred to some apparently accidental circumstances, and in this sense the pumps of the Grand Duke of Tuscany, Cosmo, patron of Galileo, are referred to as the cause of what in the end proved a very fruitful inquiry.

The Grand Duke's pumpmakers found that their lift-pumps could not be made to *draw* water more than 30 feet, or thereabouts, and the question of the cause of this difficulty was referred to Galileo for solution. The philosopher ascribed the rising of water in the lift-pump to the weight of the atmosphere:—"The heavy air," said he, "rests on the water in the cistern and presses it with its weight. It does the same with the water in the pipe, and therefore both are on a level; but if the piston, after having been in contact with the water, be drawn up, there is no longer any pressure on the surface of the water within the pipe, for the air now rests on the piston only, and thus occasions a difficulty in drawing it up. The water in the pipe, therefore, is in the same situation as if more water were poured into the cistern,—that is, as much as would exert the same pressure on its surface as the air does. In this case (the case of a head of water), we are certain that the water will be pressed into the pipe, and will raise up the water in it, and follow it till it is equally high within and without. The same pressure of the air shuts the valve during the descent of the piston." There was at that time an old dogma about "nature's abhorrence of a vacuum;" it had been considered to afford an explanation of the rising of water in the lift-pump. Galileo met the very obvious objection "that if the rise of the water was the effect of the air's pressure, it would also be its measure, and would be raised and supported only to a certain height." He adduced this as a decisive experiment. "If the horror of the void be the cause," said he, "the water must rise to any extent, however great; but if it be owing to the pressure of the air, it will only rise till the weight of the water in the pipe is in equilibrio with the pressure of the air, according to the common laws of hydrostatics." And he adds, drawing his experience from that of the pumpmakers, "that this is well known, for it is a fact that pumps will not draw water much above 40 palms, although they may be made to propel it, or to lift it to any height." He then makes an assertion which he says if true will be decisive. "Let a very long pipe, shut at one end, be filled with water, and let it be erected

perpendicularly, with the close end uppermost, and a stopper in the other end, and then its lower surface immersed into a vessel of water,—the water will subside in the pipe on removing the stopper till the remaining column is in equilibrio with the external air." This experiment he proposes to the curious, saying, however, that he thought it unnecessary, there being such abundant proof of the air's pressure.

The experiment with a column of water would at that date have been one of difficulty, and it remained at the time untried; but after the death of Galileo the subject fell into the hands of his pupil, the talented Torricelli, who argued that if the column of water of 34 feet was supported by the weight of the atmosphere, other fluids would be supported or balanced by the atmosphere to heights inversely as their gravities, and that quicksilver, being $13\frac{6}{10}$ times heavier than water would be supported only 30 inches. So he took mercury and a glass tube, and filling the tube with the mercury, and inverting the tube in a basin of mercury, and removing his finger from the lower opening, he found, to his delight, that the predictions of his much-loved master and his own calculations were at once verified, for the mercury sank in the tube, and remained at 30 inches.

In France, the learned Pascal devoted a close attention to this experiment of the Torricellian tube. He reasoned that if the column of mercury was supported in it by the weight of the atmosphere, it should follow that on ascending to an altitude the column should fall progressively and proportionately as so much air was left under foot. Pascal, unable to leave Paris, deputed a relative to try this experiment for him. Two barometers (for tubes thus filled with mercury are now called barometers) were filled and compared, and while one of them was observed in the garden of the Convent of the Friars Minims, at Clermont, in Auvergne,—the other barometer was observed simultaneously at stations on the mountain called "Puy de Dome," and it was thus found that as the tube was carried up the mountain the column of mercury fell, and on returning down again into the lower atmospheric regions, the additional pressure of the full column of air was brought to bear on the cistern of mercury, which metal again rose in the tube.

Thus was discovered the use of the mountain barometer for measuring heights. Further observation, moreover, soon showed that, at the same level, the pressure of the atmo-

sphere altered within a limited range from time to time,—that these alterations of pressure occurred in accord with alterations of the weather, and thus the Torricellian tube became the weather glass or common barometer.

As the air is not only a ponderable substance, but also, in common with all gases and vapours, an elastic fluid,—as a given bulk of it may be squeezed into a smaller bulk by pressure, and will expand to its original bulk as soon as that pressure is removed, it follows that in ascending a mountain, or in a balloon, we not only liberate ourselves from the pressure of the fraction of the whole column which we have left under our feet, but a small columnar measurement near the earth's surface is found to be equal to a larger column in the higher strata; for as we pass upwards the air is found to become gradually more and more rarefied. The air nearest the earth's surface bears the weight or pressure of the whole column above it, and is compressed thereby; it balances the compressing force by its elasticity: in fact, its elasticity under any pressure is always equal to the force with which it is compressed, so that the aerial column from the earth upwards may be compared to a series of heavy steel springs, piled one over the other,—the topmost fully expanded, the lowest of the series bearing the greatest weight and therefore most compressed,—the others, from the bottom upwards, less and less compressed because gradually less loaded. If we progressively remove the weight of the top spring, those beneath will expand, until, when all are removed from the lowest of the series, it will have recovered its full dimensions.

The knowledge of the physical properties of air, obtained chiefly by the aid of the two instruments, the barometer and the air-pump, prepared the way for a knowledge of its chemistry.

Nitrogen, which forms about four-fifths of the bulk of atmospheric air, was discovered by Rutherford, Professor of Botany in the University of Edinburgh, in 1772; and oxygen, the other chief constituent was identified by Priestley and Scheele, independently of each other, in the years 1774 and 1775. Lavoisier, as I explained in my first lecture, superseded the old theory of Phlogiston by a satisfactory theory of combustion, which has proved a stimulus and valuable aid to inquiries concerning the chemical nature of gaseous bodies.

I present to your notice a table showing the components

of the atmosphere: in 100 parts of air deprived of minor constituents, we have—

	By volume.		By weight.
Nitrogen	79·19	or	76·99
Oxygen	20·81		23·01

You observe that for one volume of oxygen there are very nearly four volumes of nitrogen, and as nitrogen is a very little lighter than oxygen, the proportion by weight does not largely differ from that by volume.

Besides these elements (the nitrogen and the oxygen), aqueous vapour is present in the air. Its average proportion may be stated at 1·4 per cent. by volume, or 0·87 per cent. by weight: and carbonic acid, also always present, exists in the average proportion of 4 parts in 10,000 by volume, or 6 parts in 10,000 by weight. Carbonic acid is in fact of greater specific gravity than the other constituents. The nitrogen, oxygen, aqueous vapour, and carbonic acid of atmospheric air are not chemically combined with each other, but air is a mere mechanical mixture of these several bodies, with certain other minor constituents also in mechanical admixture.

But as nitrogen is somewhat lighter than oxygen, and as carbonic acid is much heavier than either of them, as the expansion and contraction of gases for changes of pressure and temperature is the same for all gases whatever, so that in a mixture of two or more of them, subjected to alterations of pressure and temperature, the relation of the specific gravities of each to the others remains constant, it may be asked *how it happens* that these bodies, *possessed* of *gravity* and *merely mechanically mixed*, *do not subside* according to their gravities, with a stratum of the dense carbonic acid occupying the lowest level, the oxygen collected above it, and over all, the lighter nitrogen, which in an attenuated condition in the upper regions would be lighter than either of the other gases when similarly rarefied.

The answer to this question depends upon remarkable properties belonging to all gaseous bodies, and causing them to form equable mixtures with each other, even in opposition to the force of gravity.

The atoms of the most solid bodies are widely removed from each other; those of gases, so much more attenuated than solid bodies, are far more remote; they repel each other, so that gases, as they are removed from the action of

gravity, expand more and more, until they become of extreme tenuity. One gas will expand into the space occupied by another gas as though the latter were a void; they will *interpenetrate* as though the space of each were virtually a vacuum to the other, and until an equal mixture of the gases results. The *only difference* between the expansion of one gas into the space occupied by another, and into a void, is *that* which concerns the *time* of diffusion; the result will be slower than when a vacuous space is concerned. The one gas, into which the other gas expands, will act as a mechanical obstacle, but will in no way prevent the ultimate result of an uniform mixture.

Carbonic acid is so heavy that it may be poured from one jar to another, as water is poured; but if this heavy carbonic acid is left in an open vessel for a short time it will gradually expand into the air above it, and diffuse itself into space; while it remains, a taper immersed in it is extinguished; but after a short time it will have expanded out into the lighter atmosphere, and then, in the air which replaces it, a taper will burn. The mobility of gases in this way bears relation to their specific gravities, the lighter being the most mobile, and soonest dissipating themselves through the space of any other gas. Dr. Graham has shown that the rate of diffusion of various gases is inversely as the square roots of the specific gravities of each. Thus hydrogen, being one-sixteenth the specific gravity of oxygen, will escape through a fine orifice when under a definite pressure, four times as rapidly as oxygen would,—four being the square root of sixteen. If a tube closed at the top with a disc of dried plaster of Paris be filled with hydrogen, and its lower open end be placed in water, the hydrogen will escape out of the tube through the pores of the plaster, so much faster than the atmospheric gases can pass through the pores to expand into the hydrogen, that the gas in the tube will rapidly diminish in amount, and a column of water will rise in the tube to compensate the deficiency. These simple, but expressive facts show that there are properties belonging to bodies in the gaseous state which counteract any tendency, such as mixed gases might otherwise have, to separate from each other by gravitation. This remarkable property of diffusion, of which all gases are capable, is a power continually exerting itself for maintaining an uniform composition of the earth's atmosphere, and compensating all changes, including those brought about by

the organic kingdoms, such as are now, and have been, taking place for countless ages past.

From these considerations let us proceed to acquaint ourselves with the major constituents of atmospheric air, namely, with the nitrogen and oxygen.

If phosphorus be burnt in atmospheric air it combines with and removes the whole of the oxygen, so that what remains is nearly pure nitrogen; a gas void of taste, smell, and colour, and which will neither support life nor combustion. It is to a great extent characterized by these and other negative properties. 100 cubic inches of nitrogen gas at mean pressure and temperature weighs 30·16 grains.

The oxygen is a gas void of taste, smell, and colour; 100 cubic inches of it weigh 34·6 grains. It is a powerful supporter of combustion, a most powerfully chlorous or electronegative element. Carbon burns in it with vivid combustion, converting the oxygen into its own bulk of carbonic acid. Even the diamond may be consumed in it, as I showed in my first lecture. Phosphorus burns in oxygen with evolution of a dazzling light; and a white fume of phosphoric acid, soluble in water, is the result. Even iron may be burnt in oxygen, more readily than wood burns in atmospheric air. The energy with which bodies burn in pure oxygen is far greater than would accord with the condition of things at present obtaining on the earth's surface.

While speaking of oxygen it will be necessary to say a few words concerning Schœnbein's remarkable discovery of ozone, a body of high interest, which has been closely studied by chemists of the first rank, but of which our knowledge at this date is by no means complete.

Ozone, present in the atmosphere in minute quantities, is a variable constituent. Its properties relate it in many respects to oxygen, but certain other of its properties are widely different from those of oxygen. It is regarded as a modified form of oxygen in which certain of the properties of this element are exalted. It may seem strange that an element, a body *sui generis*, should have any other than fixed properties; but yet we know cases in which elementary bodies assume several forms, which are quite distinct in external physical properties, and in certain of their chemical aptitudes. The diamond, plumbago, and charcoal, are three very different forms of carbon. Pure sulphur may exist at common temperatures as a brittle solid, or as an elastic material like indiarubber. Common phosphorus cannot be

handled without danger of igniting it; but amorphous phosphorus, equally pure with the common form, may be carried loosely in the pocket, and is quite stable under conditions in which common phosphorus is rapidly oxidized. Common phosphorus may be converted into amorphous phosphorus, and *vice versa*, without any addition of material substances. At certain definite temperatures the one is transmuted into the other. It is with ozone and oxygen as with these examples; ozone differs widely from oxygen in many of its properties, ozone liberates iodine from its compound with potassium, and this freed iodine strikes a purple tint with starch,—an effect which common oxygen cannot perform; ozone rapidly oxidizes silver, which change free oxygen cannot effect; ozone bleaches indigo, and yet ozone appears to be no more than a modified form of oxygen.

When an electric discharge is passed through atmospheric air (this refers especially to the silent or brush discharge), ozone is generated, and the peculiar odour created during the use of the common frictional electrical machine, or by the discharge from the "secondary" of an induction coil, is clearly due to the generation of ozone. Ozone is denser than common oxygen, from which it appears to differ in its molecular arrangement. I will endeavour to afford an idea concerning this point:—let me explain in the first place that it is regarded by Sir Benjamin Brodie, and all other chemists, as true that all chemical combinations are accompanied by a simultaneous chemical decomposition. When two elements combine, this chemical decomposition is not wanting. But it may be asked, if the elements are incapable of resolution into more simple parts, how can a decomposition take place when combining elements only are concerned? In answer to this question it must be explained that although oxygen gas consists of oxygen alone, the foundational atoms of oxygen are combined with each other into molecules, each of which consists of a pair of atoms, so that each molecule is what may be called an oxide of oxygen, the atoms thus combined bearing relations to each other comparable to those of the chlorous and basylous elements in ordinary binary compounds of two elements,—say to those of chloride of hydrogen, for example. One atom of the oxygen represents the chlorine, the other the hydrogen, in each compound, and they have different electro-chemical relations in conformity with this view.

Speaking of the oxygen molecule, it may be explained that

there are facts which go to show that when these molecules are broken up so as to let one or other of the constituent atoms free, its force of combination will depend upon the nature of the decomposition, or in other words upon whether it is the chlorous or basylous atom we are liberating, by appropriating its opposite. Now, in ozone, it is understood that to an ordinary molecule of oxygen an atom of chlorous or negative oxygen is added into combination; if the molecule of common oxygen be represented as constituted of a plus and minus atom $\oplus \ominus$, then the ozone molecule would be represented as a group of three oxygen atoms, two negative and one positive $\ominus \oplus \ominus$; and to the facility with which the extra negative or chlorous atom of oxygen is liberated, so as to leave the ordinary neutral balanced molecule of oxygen, the exalted oxidizing power of ozone is attributed.

There is according to Schœnbein also an antozone, which differs from ozone by containing in addition to the components of the neutral molecule, a basylous or positive atom of oxygen; it would be represented as consisting of two positive atoms and one negative atom of oxygen in its triple molecule $\oplus \ominus \oplus$. We have no time for paying attention to the researches of Dr. Andrews, of Belfast, and others, upon which these interesting views concerning the nature of ozone are founded.

From these remarks concerning ozone, let us return to the major constituents of atmospheric air,—the oxygen and the nitrogen. I have shown you the avidity with which combustibles burn in oxygen, and that burning bodies are extinguished when plunged in nitrogen: let me now add, that if we make a mixture of one volume of oxygen to four volumes of nitrogen, a taper plunged into it will burn just as it does in the atmosphere, neither more nor less energetically; so that we may regard the nitrogen as diluting the oxygen, and tempering its chemical activity.

There are no less than five definite chemical compounds of nitrogen and oxygen known; yet in atmospheric air these elements are merely mechanically mixed, and not in a state of intimate chemical combination: the identity of each element is preserved in the mixture. Nitrogen gas is indeed an anomalous element; slow to combine, it cannot be burnt in oxygen as hydrogen can be burnt; nevertheless, it forms many compounds in its own peculiar way, and certain of these nitrogen compounds are of the highest importance in the great scheme of mundane nature. Nitrogen combines

with hydrogen to form ammonia, and nitrogen combines with oxygen to form powerful acids. If a stream of electric sparks be passed through air, we soon observe that orange-coloured fumes are produced, and these afford proof that a chemical union of small proportions of nitrogen and oxygen has been effected.

Continued atmospheric electrical disturbances and thunder storms effect a regulated combination of nitrogen and oxygen gases, with production of nitric acid, which is brought down in the rains to the soil, becoming a source of nitrogenous food to the vegetable kingdom. Growing tissues, both vegetable and animal, are rich in nitrogen, and the primary source of all this nitrogen is the nitrogen gas of the atmosphere, whose properties are so nicely balanced that, instead of seizing all the oxygen of the atmosphere by a violent combustive process, and thus converting it into nitric acid, which would rain down as aqua fortis, is yet capable of yielding constant supplies of those particular compounds which are indispensable nutrients of the vegetation of the globe, and without the sustained supply of which, animal life would soon vanish from the scene.

But the relations of the oxygen and carbonic acid gases of the atmosphere are as remarkable as those of the oxygen and nitrogen. The vegetable kingdom builds, while the animal kingdom is ever consuming what has been built up in the tissues of vegetables; and these two kinds of change are not only complementary to each other, but are so arranged as to keep in equilibrium the proportion of oxygen and carbonic acid in the atmosphere. Plants breathe through their leaves and fleshy tissues in a manner which may be compared to the breathing of animals through lungs, gills, and spiracles; but the breathing of vegetables involves chemical changes of a nature different from those of the breathing of animals. In the respiration of vegetables, under the influence of sunlight, the atmospheric carbonic acid is decomposed, its carbon is fixed in the plant as a constituent of its growing tissues, and of the starch, lignin gums, colouring matters, resins, wax, essential and fixed oils lodged in those tissues. The carbon is fixed, and free oxygen is liberated, and plants during their lives are ever treasuring up vegetable products. The animal economy has no power of its own of forming tissues of its own from constituents of the soil or from atmospheric gases; animals therefore live directly or indirectly on the vegetable king-

dom; for even when flesh food is consumed, this is primarily derived from a vegetable source. In the animal functions there is a continuous consumption and large waste of the vegetable foods; what is consumed is much greater than the proportion treasured up and forming the constituents of the animal economy, and in the process of animal respiration, instead of the decomposition of carbonic acid and fixation of its carbon, eliminating the oxygen, the converse takes place; the atmospheric oxygen is consumed, and carbonic acid is expired. It is only necessary to force a stream of expired air through lime water to show the abundant emission of carbonic acid, by the copious precipitate of carbonate of lime which is formed.

The animal and vegetable kingdoms are always compensating each other's effects upon the atmosphere; the vegetable kingdom is always replacing carbonic acid by its bulk of oxygen; the animal kingdom is always appropriating oxygen and substituting carbonic acid; and although there are also geological changes by which large volumes of carbonic acid are poured out into the atmosphere, yet by the agency of rain, dissolving the latter and carrying it to the soil, and by the vital functions of both plants and animals as already explained, the nitrogen, oxygen, and carbonic acid gases of the great aerial ocean are maintained, with marvellous exactitude, in those proportions which are in every way most suitable for supporting the life and business of the globe.

Besides these major constituents of atmospheric air, there are no doubt other gases and vapours present in minute proportions; free hydrogen, carbonic oxide, and light carburetted hydrogen, or marsh gas, are among these; the latter being constantly evolved from the mud of stagnant pools and swamps. Many manufacturing processes pour volumes of gaseous impurities into the atmosphere, often to the detriment of the neighbouring vegetation. There are the poisonous metallic fumes from the melting of metals, cyanogen compounds from the iron furnaces, muriatic acid gas from the soda manufacture; but all these impurities are either consumed during thunderstorms, or washed out by rains. It is only in the immediate vicinity of such sources of atmospheric contamination, or by confining air in closed spaces, that the baneful effects of impure air are experienced. Concerning impure air I shall have something further to say in the last lecture of the present series, on "Household Chemistry."

Besides the constituent gases of the atmosphere, there are also present in it another class of bodies,—fine particles of solid matter, which may be collectively designated as *dust*. Even where the air is in comparative repose, and appears to casual observation free from impurities of the kind, these fine mechanically-suspended dust motes are seldom absent; as may be seen whenever a beam of sunlight is let into an otherwise darkened room. This dust is partly of a mineral nature,—the finer particles of soil, dried and dispersed in the winds; but there are also present organic particles of animal and vegetable origin. Besides fibres of wool diffused from our clothing, and other debris of like character, there are also among the organic particles of the air spores of fungi and germs of animal life, wanderers which, as soon as they find a proper pabulum, settle down and grow into plants or animals, which in their turn people the air with myriads of germs. The spore of the lycoperdon, the common puff-ball, is of such dimensions that it would take four thousand million of them to occupy, as closely as they could be packed, a cubic inch. The growth of the plants and animals which spring from these germs is an active cause of the fermentations and decays of animal and vegetable substances, as may be instanced in the dry-rot of timber, during which the destruction of the tissues of the timber, and the simultaneous luxuriant growth of a fungus, accompany each other. I shall refer more particularly to this subject in my lecture on "Food Preservation," for there is not time for entering upon it at present.

I will conclude these observations on the chemistry of the atmosphere by pointing out the readiness and punctuality with which its various functions are fulfilled. The demands upon the atmosphere are, and for ages have been, unceasing, and it is always ready and capable. At night its functions are very different to those required during daylight; during the night the forest trees exhale carbonic acid, but as soon as the sun rises on the landscape every green leaf commences to seize carbonic acid, to fix its carbon, and to render back its oxygen. When the sun rises on a continent in the morning, the atmosphere at that part of the globe is prepared for another day's work;—from day to day,—from year to year,—from century to century,—from cycle to cycle,—always ready to sustain the vegetable kingdom with sufficient carbonic acid; and at the same time to supply the animal

kingdom with oxygen, tamed to sobriety of action by a just admixture of nitrogen; and without overdose of that carbonic acid which, for the sake of both animal and vegetable life, must be present in proportion sufficient for the nourishment of the latter.

I recommend this great pneumatic system of our globe,—so perfect, so simple, so enduring,—as a subject of thought which will exalt the views of all who consent to devote a patient attention to it.

LECTURE V.

ON FOOD PRESERVATION.

DELIVERED BY GEORGE FOORD,

ON 10th NOVEMBER, 1870.

It will be my endeavour, this evening, to render an account of those principles upon which are based the several methods for the preservation of animal and vegetable foods;—those principles upon which are based the methods at present in use, as well as those recently proposed, but not as yet adopted into practice.

I admit to you, at the outset, that when I shall have done my best, the result *must,* for several reasons, prove a very imperfect one. On the one hand, our subject is of great extent; on the other, our time available for its consideration is, out of all proportion, limited. Experimental illustrations of the processes of food preservation are beyond my reach. Some departments of the chemistry and physics of the subject are at the present date but imperfectly understood, and as for the art of food preservation itself, we are only on the threshold of its economic practice.

The importance of this practice of food preservation to the human race must be evident to all intelligent minds. The surface of the globe,—the sea and land,—considered as a whole, produces food in abundance, and in astonishing variety; but what is thus produced requires distribution. The glut of one country must be deported to others, where it is in demand. Navies must be victualled;—the soldier in the garrison,—the fatigue party,—the watcher in the lighthouse,—the pioneer

explorer, must each be provisioned. Our harvests of land and sea must be carefully stored, as well as frugally expended, so as to last out until the plenteous season again comes round; and all these important requirements are aided whenever we can put the food substance into some form which is secure from decay. To effect improved methods,—methods of preserving food which are at the same time facile, reliable, and inexpensive,—is to facilitate the storing and distribution of it, to banish scurvy from the navies of the world, and to supersede local famines by an universal plenty.

In entering upon our subject let me say a few words concerning the composition of food. Let me remind you of what was said in a former lecture, namely, that animals and vegetables are composed of exactly the same substances, which differ only in the proportions in which they are present. On our table of the elements, those entering into the animal and vegetable kingdoms are indicated by coloured discs; the major constituents are marked each with a blue disc,* and those which are more rarely present, or which are present only in minute proportions, are marked with a red disc.§ In animal flesh and fats,—in the substance of grains,—in the pulps of fruits and tubers,—in all food materials, whether of animal or vegetable origin, these elementary substances, marked in our table, are combined into what is commonly called proximate principles,—that is to say, compounds of carbon with hydrogen, oxygen, sulphur, nitrogen, phosphorus, and the rest of them.

With many of the proximate principles of the organic kingdom we are quite familiar; cotton wool is a familiar example of nearly pure cellulose or woody fibre; we are acquainted with starch, cane sugar, with tartaric and citric acids, with the constituents of fats, such as glycerin and stearic acid, with albumin in the white of egg; we know many of these building materials, which are employed indiscriminately in both the animal and vegetable kingdoms, and out of which all living things are made.

An example or two will assist our conception of the apportionment of these proximate principles, in building up vegetable and animal structures. Take wheat as an example for this purpose.

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* With an asterisk, in appended table of the elements.

§ With a †, in appended table of the elements.

The average per centage composition of wheat may be taken as:—

Water	14·0 parts
Gluten...	12·8 „
Albumin	1·8 „
Starch	59·7 „
Sugar	5·5 „
Gum	1·7 „
Fat	1·2 „
Cellulose (Fibre) ...	1·7 „
Mineral ashes	1·6 „

These constituting 100·0 parts of wheat.

The gluten and albumin contain nitrogen, while the starch, sugar, gum, vegetable fat, and cellulose are composed of carbon, hydrogen, and oxygen only.

Take another example.

Lean beef contains in 100 parts:—

Water	50· parts
Gelatin	7· „
Fibrin and Albumin...	8· „
Fat	30· „
Mineral ash constituents	5· „
Total	100

Of these constituents the fibrin, gelatin, and albumin are rich in nitrogen.

Examples might be multiplied, but these two are sufficient for illustrating the building up of animal and vegetable structures from these proximate or compound constituents, and will lead us to the point to which I desire next to refer.

We all know that animal substances are more prone to fall into putrefactive decay than vegetable substances; in warm weather, a few hours will turn a newly-slaughtered carcass into a fetid, corrupt mass; while under the same influences of exposure to air at a warmer temperature, vegetables are, as a general rule, much more permanent. But if I take wheat flour, and wash out the starch so as to leave a residue, consisting for the most part of the gluten, it will be found that this gluten is far more prone to decay than the original wheat flour; while the starch is so permanent a substance, that while kept in the dry state it will remain for years quite unaltered. Starch contains no nitrogen; the dried gluten of wheat con-

tains about 16 per cent. of nitrogen; and it may be stated as a general rule that organic substances rich in nitrogen, whether of animal or vegetable origin, are far more liable to decay than those organic substances which are nitrogen free. Sugar contains no nitrogen, and hence sugar candy,—sugar in the dry crystalline state is quite as permanent as starch under like conditions. It is, in this state, as permanent as salt or alum, or similar compounds of purely mineral origin. If sugar be dissolved in water so as to form a very strong syrup, this syrup may be kept for a very long time without any obvious change: it is true that crystals of sugar candy may separate from the thick fluid, but the sugar itself remains unaltered in its chemical nature. If to this strong syrup more water be added, so as to make a thin saccharine solution, the case is materially altered by that addition. After a day or two the solution begins to grow turbid, bubbles of gas rise through the fluid,—fermentation sets in,—sugar gradually disappears,—alcohol is formed.

If nitrogenous principles, such as albumin or casein, gluten, &c., be also present in our saccharine solution, the activity of the fermentation is promoted, and the result is rendered more complete, for before long all the sugar will have disappeared, having been converted into alcohol on the one hand, and carbonic acid, which escapes as gas, on the other. If the temperature be high, a further change may take place, all or a part of the alcohol may be oxidized, with formation of vinegar or acetic acid. Our sugar has decayed by fermentation, into carbonic acid and alcohol, or even into carbonic and acetic acids.

Now I wish you to observe that there are certain conditions which favour this change of the sugar,—namely, the presence of a sufficient proportion of water, the maintenance of a suitable temperature, and exposure to the atmosphere. If our newly-boiled solution of sugar is kept well guarded from contact with the air, it does not ferment. If it is kept at a very low temperature, even though exposed to the air, it will not ferment; or if it be a very strong syrup, that is to say, if insufficient water is present, it will not enter into spontaneous fermentation.

But if we add a little of any fermenting fluid to it, even without exposure to the atmosphere, it will,—the other conditions of temperature and sufficient dilution being observed,—commence to ferment, so that the atmosphere clearly supplies something which answers the same purpose as adding a

little fermenting fluid, or a drop of yeast, that is to say, "a ferment," to our weak syrup; and here we gain a clue to this natural process of fermentation. The explanation is to be found by examining a drop of the fermenting fluid, or a particle of yeast, under the microscope, when we find that the fluid is permeated by yeast particles, which consist wholly of little vegetable cells, each one of which is a minute plant or fungus. These yeast cells can be seen to grow and bud and multiply, by watching them in the field of the microscope; their rate of increase reminds us of the familiar problem concerning the nails in the horse's shoes. They not only increase by budding, but they also burst, scattering from a single cell a profusion of germs, each of which may become an active yeast cell,—the prolific mother of a countless race.

The effects of the yeast cell upon the saccharine fluid have been closely investigated, but the way in which these cells bring about chemical changes, converting sugar into alcohol and carbonic acid, is not understood. This subject of fermentation you will understand to be a very extensive one; there are many kinds of fermentation, many varieties of ferment, of which our instance of the beer yeast fungus may be accepted as a fair example.

But if instead of adding yeast to our solution, we can start its fermentation by mere exposure to the atmosphere, may we not infer that organic germs, of the nature of ferments, are floating in the air? There is indeed ample proof that such bodies are nearly everywhere present, that we breathe them, and that they settle down upon the surfaces of all fluids and solids,—upon whatever is exposed to the air. In my last lecture I had the pleasure of showing you how minute and numerous were the spores of the puff ball, itself a species of fungus; I showed you how easily these spores are disseminated as an extremely fine dust through the air, and I told you that I had calculated from the measurement of their dimensions in the field of the microscope, that it would take four thousand millions of them, packed as closely as possible, to occupy a cubic inch of space. If we know that when the puff ball is ripe it bursts and scatters legions of its spores into the winds, we may infer the probability of a similar distribution of the germs of other species. But we are not dependent on mere inferences of this nature, for we have conclusive proofs of the prevalence of spores and germs of many kinds of vegetable and animal life generally diffused through the atmosphere. When a beam of sunlight enters through

an aperture in a window-shutter into an otherwise dark room, we can see the motes moving with every breath of air across the beam; but as they rise and fall and whirl in spirals, we cannot single out any one of them to say "that is certainly a vegetable germ, which will start into growth as soon as it meets with a suitable fluid or other pabulum."

Very refined experimental means are required for enabling us to speak with certainty on this point; means such as Pasteur has employed, and to which I will now briefly direct your atttention. Pasteur, by means of a fall of water, drew a current of air through a glass tube in which a wad of the purest guncotton had been previously placed, and in this way he was able to sieve out all the spores and germs and dust particles from an ascertained volume of air. By removing the wad of guncotton and dissolving it in a mixture of alcohol and ether, the spores and dust remained for examination. But particles of starch, or the pollen of flowers, or minute filaments may be mistaken for spores of fungi or animal germs; in fact, it may be said that what Pasteur obtained as a residue on dissolving his gun-cotton were *spore-like bodies.* Starch granules could be detected by iodine water, which readily colours them violet, but this still left the chief question undecided, and, in short, the only way of proving that a microscopic cell is a spore is by its growth and multiplication. With the object of establishing this point in reference to the small bodies, thus filtered out of the air, Pasteur employed another method, which I hope to make clear to you by the following explanation.

At the temperature of boiling water, albumin is coagulated, the yeast plant is killed and fermentation is stopped. If a fermenting fluid, after being thus boiled, is exposed to the air, it will before a few days are over, again start into fermentation; yet after the boiling, all that is requisite for supporting a fermentation remains in the fluid, excepting only the vegetable ferment, and this is soon acquired a second time from the atmosphere. Pasteur made use of these facts. He added yeast to sugar solutions and other fluids capable of fermentation, and charging glass globes with the mixture, he boiled the contents of the globes and sealed them hermetically: his sealed globes contained a fluid highly susceptible of fermentation, but which could not ferment as long as the globes remained sealed, because of the absence of all active ferments; and because of the impossibility of any ferment gaining access to the fluid through the substance of the glass. These

globes were tested by placing them in a chamber maintained at a temperature favourable to fermentation. These globes were applicable to two very important classes of experiment. When he opened one of these globes from which the air had been expelled, by boiling the fluid contents;—when he opened this globe by cutting off the extremity of the sealed tubulus, a sample of air, at the place where this was done, rushed in, and with a blowpipe the globe could be immediately sealed up. Now, if the air which rushed in took in with it any suitable ferment spores, these would soon start fermentation in the fluid, and would multiply, and could be eventually examined under the microscope. He also employed his bulbs for a second purpose; namely, for ascertaining the nature of germs and spores collected in his wads of gun-cotton or asbestos, during exposure to currents of air in the manner already described. In these latter experiments very great precautions were observed, and very ingenious means for the introduction of the little wads, or pellets, were employed. His asbestos plugs were subjected to a red heat before exposing them to the current of air to be tested, and the air introduced with them into the bulbs was carefully dessicated, by passing it through a red-hot platinum tube; this air, freed from all kinds of germs, was cooled before bringing it into contact with the asbestos plug, with which it was to pass into the bulb.

In testing samples of air, directly, by means of his bulbs, Pasteur obtained remarkable results. He opened his bulbs at different heights above the sea-line; first, on the open plain, at a situation remote from human habitation, at the foot of the heights which form the first plateau of the Jura mountains. He opened others at 2800 feet (850 metres) above the sea-line, and another series at Montanvert, near the Mer de Glace, at an altitude of 6500 feet (2000 metres). Of the twenty bulbs opened on the plains, eight fermented; of twenty opened on the first plateau of the Jura, five only showed evidence of fermentation; and of the other twenty, filled with air at Montanvert, in a strong wind, blowing through the deepest gorges of the glacier of Bois, one only showed change; so that the higher strata of the air contain fewer organic germs than are present in an equal cubic space in strata at lower levels. Great precautions were taken in these experiments. The neck of each bulb was first heated in a spirit lamp, to destroy all extraneous adherent germs; the neck was then incised with a steel point, and, holding the bulb high over his head,

and pointing its projecting tube towards the wind, the operator then broke off the extremity by means of steel pincers.

In one remarkable instance, air at a low level was ascertained to be quite, or very nearly, free from these germs. The French Imperial Observatory is built upon vaults, and these vaults or caves are situated at the zone of invariable temperature; the air in them is therefore quite still, quite free from currents, and the dust in this tranquil atmosphere has full opportunity of gravitating to the floor line. Very considerable precautions against agitating the air, and against raising dust particles into it were necessary, but when these were duly observed the results were of a very interesting character. Ten bulbs were opened in these caves, and simultaneously eleven similar bulbs were opened in the courts of the Observatory, twenty inches above the level of the ground, a light wind blowing at the time. The two sets of these bulbs were then all placed together in a stove, maintained at from 77° to 86° Fahr. One only of the ten opened in the cave showed any signs of organic growth or fermentation, while all those opened in the court produced organic beings, either infusoriæ or vegetable forms.

You understand, then, that the air teems with minute germs in sufficient abundance for attaching themselves, and growing and multiplying wherever a fitting pabulum presents itself. Moreover, as in nature, the materials of what has died,—the materials of the dead trees in the forest, and of the carcass stretched on the plains,—the matter of effete forms,—old, but ever new,—unimpaired in its chemical and other foundational properties, and imperishable,—is required, over and over again, for the construction of new forms. As this economy is imperative; to these minute and almost invisible particles floating in the air is deputed a function of the highest importance, namely, that of promoting the fermentation and decay of all exposed effete organic matter; and this they do so effectually, that once taking hold of such matter,—one single germ of a suitable kind alighting on it,—it is doomed to changes which go on at a continually-accelerated speed until nothing of the original substance is left.

Of course there is a great variety of the changes of which I am speaking, and when these minute but irresistible germs have commenced the work of destruction, the insect world often comes in to contribute its share towards the work of spoliation. In the dry rot of timber the growth of the spore is largely at the expense of the albuminous constituent of the

wood, that is to say, of that constituent which is rich in nitrogen; the fungus ramifies through the tissues of the wood, and so thoroughly disintegrates it that what is not appropriated and consumed by the fungus itself is soon otherwise disposed of. The cellulose or woody fibre is altered by a collateral action, very much as sugar is converted into carbonic acid and alcohol during the fermentation of wort or must.

When paste is exposed to the air the fungus spore soon alights on it, and so grows into little tufts, which spread over the whole surface, growing at the expense of the paste, till neither starch nor gluten is left. A breath of air on the mouldy surface will distribute a pungent dust, which the microscope reveals as millions of spores; these go to the four winds to find other paste-pots on which to luxuriate. A ripe lemon placed on a shelf is liable to a fungous decay, especially where its weight brings its under side in contact with the surface on which it rests. At that point evaporation is arrested, there the surface becomes moist, there the supply of air is limited, and therefore favourable to decay. It is not long before the germ insinuates itself. A verdigris green-coloured spot appears, the skin softens, the fungus pushes its way into the fruit, ramifies throughout it, converts it, destroys it thoroughly. The outer coverings of vegetable and animal bodies,—the skins of animals, the rinds of fruits,—are protections against the insinuation of these germs; these coverings are under ordinary conditions a sufficient protection; but, as instanced in the case of the lemon, as soon as the conditions of natural healthy growth are violated, the chances of the spore from that point commence, and sooner or later the spore becomes the victor. Grains denuded of their skins are especially subject to decay; rice is an instance of this; a little moisture, and a somewhat high temperature, as that of a ship's hold, will soon convert a cargo of sound rice, denuded of its husk, into a reeking mass of corruption.

All kinds of vegetable and animal juices, exposed to the air, are subject to decompositions of the kind considered, and during which either vegetable or animal growth takes place. The various fluids suffer changes peculiar to each instance, and many of these changes pertain to the growth of a particular organism. The fermentation of milk,—the lactic acid fermentation, feeds a fungus quite distinct from the fungus of beer. The mould of cheese is characteristic of that animal product, and, as I have already hinted, forms of life, far higher than vibrios (of which the eels of paste, as they have been commonly called,

are one variety),—far higher forms than vibrios,—are often active promoters of decay. Acari play a not insignificant part, and, to refer to a familiar statement, "two flesh flies, with their progeny, will consume the carcass of an ox sooner than a lion." In all, however, which concerns food preservation, these larger kinds of game are not those upon which we are required to bestow a close attention; the precautions for keeping them at a distance are well understood, and can be encompassed with ordinary care; but when, on the other hand, we have to deal with the spore floating in the air, invisible, to casual observation at least, and everywhere present, the case is different.

Before proceeding to consider the principles involved in the several proposed methods for food preservation, there is one point upon which it is necessary to devote some consideration. I wish you to understand that fermentation is decay,—that putrefaction is decay,—and that fermentation and putrefaction are but two varieties of the same kind of change. When the gases given off from a fluid or a moist mass, undergoing changes of the kind which we have been considering,—when these evolved gases are sensibly free from sulphur and phosphorus and nitrogen compounds, whenever the odour accompanying the change is inoffensive, we regard the change as a fermentation. But when these changes are accompanied by a disgusting effluvium, when ammonia is an abundant product, when sulphuretted and phosphuretted compounds are evolved, we regard the transformation which is going on as a putrefaction.

These several explanations, concerning the presence of germs in the atmosphere, and their relations to the different forms of fermentative and putrefactive decay, lead us, by a natural and easy transition, to consideration of the conditions to which it is necessary to conform whenever we attempt the preservation of food. Certain things,—certain conditions are necessary in order to enable these germs to grow and multiply, and these are the very things and conditions which it becomes our business to abstract and prevent. These ferment fungi are rich in nitrogen and phosphorus compounds,—they grow in the dark,—they grow in moist places,—and this growth is accelerated by a favourable temperature: speaking generally, by what would be called "a moist, warm, close atmosphere." If we take the fermenting wort of beer or must of wine, and boil either of them, we kill the ferment. If we expose either of them, the fermenting

wort or must, to a freezing temperature, we equally well arrest the fermentation. But at temperatures varying from 60° to 80° Fahr. these fermentations proceed with vigour. The various methods for preserving food, many of them differing so widely from others, all have this in common, viz., that they present some condition which is inimical to the growth of these lower forms of animal and vegetable life.

In the year 1799, at the mouth of the river Lena, in Siberia, an enormous elephant was discovered imbedded in a translucent block of ice, upwards of 200 feet thick. The animal was as perfect in its entire fabric as on the day when it was submerged; and when it became eventually denuded of ice, the wolves and foxes preyed upon its flesh for weeks. These ancient remains, thus revealed after so many centuries, were preserved from decay by the absence of two essential conditions. The atmospheric air was excluded, and the freezing temperature was lower than that at which putrefactive decay can take place.

The preservation of animal food, of fish and poultry, in the ice-house is quite a well-known process; the method may indeed be traced back as far as the time of Francis, Lord Bacon, who stuffed a fowl with snow in order to preserve it, and who caught his death of cold as a consequence of the experiment. When food is preserved by freezing it, no other precautions are necessary as long as the freezing temperature is maintained, but as soon as removed from the ice-house, a dew is lodged on the surface of the cold substance so removed, and spores from the air, with this moisture; and unless precautionary means are adopted, the comestibles thus treated and exposed pass swiftly into putrefactive decay. Freezing is largely employed for the preservation of food. In the market of St. Petersburg vast quantities of frozen provisions are to be found, the greater part of the year; they are cut up with axe and saw, like wood, for distribution among the retail purchasers. In Canada and other countries animal food is frozen for the purpose of land and sea carriage. There is no doubt about the preservative efficacy of freezing; but in speaking of freezing processes we are to distinguish between those methods in which natural ice is employed, and those in which a freezing temperature is obtained by artificial means, as by the evaporation of ether or ammonia, or by carbonic acid, liquified under pressure, and producing cold on reassuming the gaseous state; or by condensed air, expanding and performing work in an air engine. The several methods of Carrè, Mort

and Nicollè, Postle's, Harrison's, and other proposed plans, involve principles of this nature; concerning which it may be stated in general terms, that although these methods for the artificial production of cold are not any of them in use, on the large scale, for food preservation in Victoria, this is to be ascribed rather to the very great difficulties and expense incidental to the reduction of the physical principles involved, to the symmetry of working processes, than to any shortcoming in the principles themselves.

The absence of moisture forbids the growth of ferments. If we can manage to completely dry any kind of vegetable or animal foods, they are thus preserved from decay as long as they are retained in the dry state. Starch, and sugar, and dried fruits, and roots, and what is called jerked beef, or "charque," as prepared in Buenos Ayres, by cutting the meat in strips and drying in the sun, are instances of this method of preserving food by dessication. Isinglass, portable soup, and the dried albumin of eggs, are additional examples. The only serious difficulty attending preservation of food by dessication is the fact that precautions are necessary for preventing a partial decay during the operation, and before the water has been expelled; the result being always the most successful when, without using too high a temperature, the work is most rapidly performed. Hair and wool, hoofs and horns, are examples of bodies of an albuminous nature, rich in nitrogen, and of a chemical composition quite suitable for putrefactive decay under disposing conditions, but owing to the absence of free water in these substances, and owing to their compactness, they are among the most enduring of all animal substances.

Another mode of preservation,—one of the oldest in practice,—is that of imbuing the textures of animal and vegetable substances with chemicals, inimical to the growth of the organisms already so often referred to. Saturation with common salt is the most familiar and extensively employed of these methods. It is not that salt itself is so inimical to vegetable and animal growths, but rather that its superabundance, making the juices of the saturated food substance into brines, ensures the desired result. The brine may be replaced by other compounds; sugar may be used, so may nitre or acetate of soda; but the great cheapness of common salt, and the fact that it is in itself an essential article of food, has generally determined its adoption, on the large scale, in this kind of preservation. It has been proposed to saturate the

carcass of the entire animal slaughtered for food by injecting the brine or similar preservative through the arterial system. Morgan's patented method adopts this rapid and effective mode of distribution. Salted food is not without its defects; during the salting the proper animal juices are to a considerable extent removed, the salt meat is often hard and indigestible, the common salt contained in it is administered to the system of the consumer in an overdose, and, where the use of salt food is long continued, with injurious effect. While taking an overdose of common salt, other saline constituents of unsalted juicy flesh are wanting, the potash salts, for example, are lost in the waste pickle, and, in short, the consumer is mostly a gainer in the sense of healthful nutrition, when his preserved food is unsalted.

In smoking food, we gain the double effect of drying it to a great extent, and charging it, more or less, with constituents of the wood smoke employed. Non-resinous woods are those preferred,—beech, oak, and cedar. Kreasote is among the most active of these tarry wood smoke constituents. Kreasote is allied to the now well-known carbolic acid of coal tar, a body powerfully antiseptic and antiputrescent; a solution of which in water coagulates albumin, and is generally inimical to animal and vegetable growth. A leech or a fish placed in carbolic acid water soon dies, and what is of still more interest, if we steep any otherwise putrescible substance in such a solution and afterwards expose it, the imbibed carbolic acid will protect it so thoroughly from the attack of the atmospheric spores, that it will gradually dry up to the state of a mummy. There *(showing specimens)* are mice and fish so treated, they are as completely mummies as those in the tombs of Thebes; in fact, the use of petroleum and a desiccating process appear to have constituted the method of embalming practised by the ancient Egyptians with so much success. When a body is desiccated in this way it is perhaps preserved as perfectly as human art can ever hope to render it. Of course it is still subject to changes other than those under consideration. Atmospheric influences,—changes of temperature, and so on, may in time slowly alter it. If it be free from poisonous admixture, mites may find it a suitable article of food, and may consume it; the very preservative material may in time evaporate or suffer change. Of course nothing is absolutely permanent; but an organic body, dried and saturated with carbolic acid, is certainly but little prone to

change, under influences which would speedily destroy the same body if exposed in its natural state.

Essential oils have properties in some degree comparable to those of carbolic acid; a clove placed in common writing ink, to prevent its growing mouldy, is an example of this property, the essential oil of the clove being the preservative agent. Alcohol, too, is extensively employed for preserving fruits; when a saccharine juice is undergoing alcoholic fermentation, if the quantity of alcohol exceeds a certain strength, in the liquid, the fermentation is arrested. The alcohol, in that case, arrives at a strength at which it is inimical to the growth of the yeast plant, and what stops the career of the yeast plant, stops all further chemical change,—all further production of alcohol in the fluid which contains the yeast plant.

The acids, as a class, have marked preservative properties. Gum-water soon becomes covered with a crop of mould, but if we make our gum-water acid, with the addition of acetic acid, it may be kept for years. Gluten of wheat passes rapidly into putrescent decay, but may be kept without such change if immersed in dilute sulphuric acid. If you dissolve a leg of mutton, or a whole carcass, in sulphuric acid, employing the latter in such proportion as to leave the product slightly acid, no after fermentation can take place; spores may come to the product abundantly, but they cannot grow in the acidulous solution. Even blood, milk, ox-gall, the most perishable animal fluids, may be preserved from putrescence by an addition of acid: the acid may effect chemical and physical changes in each instance, just as the sulphuric acid dissolves both bone and muscle of the meat, but its presence in excess will prevent after decay. In putrefactive decay, ammonia is an abundant product, the decay is of an alkaline character; the highly complex fetid products of putrefaction appear to be most of them of a basic character, for if to putrid meat dilute or concentrated oil of vitriol be added, the meat is at once deodorised, the unpleasantly smelling emanations appear to combine with the acid. I mention these facts, not as being directly applicable to food preservation, but because they show a characteristic of putrefactive changes, namely, that they are of an alkaline character. The preservation of vegetables as pickles appears to depend on this antagonism of an acid solution to fermentative change. Vinegar which, as compared with mineral acids, is relatively a weak acid, must, for pickling, be tolerably strong; the one

secret of success is the taking care that it is not too much diluted by the juices of the vegetables with which it is employed. In fact, when we want the strongest acetic acid, we must make it by distillation, because, in the ordinary fermentation, as soon as a certain acidity is arrived at, the acetic acid stops further fermentation.

Food is also preserved by being enveloped in fat or saturated with oil; the fat itself, but little subject to decay, shields the enveloped food from both contact with the atmospheric gases, and from the spores contained in the air. The method, however, is not perfectly effective; solid fats are not perfectly impervious, and as ordinarily prepared they are not free from animal membrane; the impurities of the fat become musty, and before long this mustiness sets the meat which they envelope into a state of decomposition. Redwood's patented method of enclosing animal food in an outer covering of paraffin has some advantage over the use of ordinary fats. I can speak from personal inspection of samples of Redwood's method sent from England to Victoria; when completely enveloped they were effectively preserved, but if any sharp angle of bone happened to project through the paraffin, the meat below became offensively putrefactive.

Of course it is beyond available limits to mention all the preservative antiseptic agents which have been from time to time proposed. I can allude to but one or two more. Mr. Johnson, the Government analytical chemist, who has paid considerable attention to this subject, was I believe the first to propose bi-sulphide of carbon. I believe that there is sufficient evidence of its efficiency. It is rather a dangerous material to place in the hands of the inexperienced, but this may be said of phosphorus and some other materials which have come into daily use; its odour is most disagreeable, but this passes off soon after the meat, which has been preserved, is exposed to the air; expense would not stand in the way of its employment. Carbonic oxide gas, sulphurous acid, bi-sulphite of lime, and bodies of that class, destroying the vitality of the spore by deprivation of the atmospheric oxygen, are among the list of those agents which have promised to place the preserved meat question on a new footing; although so great a variety of materials and methods have been proposed, they all, I believe, involve the principles of which I have endeavoured to give a popular account, namely, that of violating one or more of those conditions which are provided in nature for the rapid destruction of effete organisms, so as to render over their components

for fresh uses;—we violate those natural conditions, and so frustrate the natural course of events.

But there is yet another method available for the preservation of food, and to which, in conclusion, I will now address a few sentences. Instead of keeping the food at a freezing temperature, or depriving it of moisture, or immersing it in acid, or saturating it with brine, or with antiseptic agents, we may hermetically seal the food in a vessel, so as to exclude the spore, and thus prevent decay. This is the method of Appert, or rather that at present in use is an improvement of Appert's method by Fastier. The food is cooked in tin cylinders, in an aqueous bath of chloride of calcium, which boils at a temperature higher than that at which plain water boils. The steam generated in the tins expels the air, and the air-freed tins are then sealed with a drop of molten tin solder, applied over the escape aperture. The sealed tins are once again heated in the chloride of calcium baths, and are finally tested by exposure for several days to the temperature of a hot closet, so as to ascertain by the cases bulging out, or by tapping them, whether the air space remains vacuous. Of course, if through any defect putrefactive decay should set in, gases are soon generated, and the difference between an air-free tin and one tense with the gases evolved during putrefactive fermentation is readily detected. The success of this process cannot depend upon a vigorously complete exclusion of air, that is a result which it would be practically impossible to effect. But, on the other hand, the necessity of re-heating the tins, after sealing them, seems to show pretty clearly that the success of the method depends essentially on killing any germ which may remain in the tin after it is effectually sealed up.

By the kindness of my friend and old schoolfellow, Mr. S. S. Ritchie, the manager of the Melbourne Meat Preserving Company, I am enabled to present for your inspection illustrations of this method, which, in Mr. Ritchie's hands is conducted with so much system and on so large a scale. The examples are such, I believe, as will speak for themselves, requiring no further explanations from me.

I have endeavoured, then, as briefly, and as clearly as lays in my power, to explain the principles involved in the various methods available for the preservation of human food. If I have succeeded in convincing you that the principles mentioned are essential to successful practice, my end will have been answered, because we are far from having encompassed

all that is desirable in what promises to become a gigantic enterprise, of increasing importance to the human race. To know that there are indispensable principles which must be observed may save fruitless labour to those who zealously endeavour to improve the practice. I do not deny that mere haphazard trials may perchance drop upon some result of value. But, certainly, with a knowledge of the principles involved, and with methodical experiment addressed to them, the probability of success is greatly increased. A man may open a diamond mine by digging in his garden; but a little knowledge as to the mode of its occurrence may greatly assist the seeker after this precius gem. It has been my aim to convince you that in order to make improvements in the preservation of food, it is necessary to study the conditions influencing its decay. The readiest means of counteracting these conditions must, *cæteris paribus*, prove the best method of food preservation.

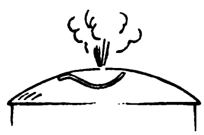
APPENDIX TO LECTURE ON FOOD PRESERVATION.

Notes furnished by Mr. S. S. Ritchie, Manager of the Melbourne Meat-Preserving Company.

ORIGIN OF THE MODE OF PRESERVING MEAT IN VACUO.

NAPOLEON the Great, on his return from his famous expedition to Russia in 1813, sought the advice of the French chemists as to some better method of preserving meat than that of salting, which had led to a great deal of *scurvy* among his troops during the march. A large reward was offered, and the prize obtained by Appert, for a process of boiling meat in hermetically sealed vessels; originally, he used glass bottles, but from the liability to breakage he soon substituted tin canisters. His methods consisted in placing the viands three parts cooked into tin canisters, which were then soldered down completely air-tight, and boiled for a number of hours according to their size and the nature of the contents; the meat so preserved was found to remain perfectly sweet, but very much overcooked, and likewise to possess a certain gaseous flavour which rendered it more or less unpalat-

able and indigestible. This method continued in use for a considerable period, until about the year 1842, when Fastier, also a Frenchman, conceived the idea of preserving meat in vacuo. At first his attempts were directed to forming a vacuum in the tin vessels by fire, but finding that impracticable, he adopted the plan of leaving a small orifice in the lid of the canister, otherwise hermetically sealed, and during the boiling process expelling the air therefrom by means of steam. This method is now in use both here and at home. The mode in which it is carried out is as follows:—The meat is, either in a raw state or partially cooked (for the purpose of reducing its bulk) placed in a tin vessel, which is then soldered down, but a small hole is left in the lid, protected on the inside by a bridge to prevent the meat swelling and stopping the orifice, thus—



The canister is then placed in a bath filled with chloride of calcium to a depth of about three-fourths of the height of the canisters. The chloride of calcium is heated by steam passing through a worm laid along the bottom of the bath, and by varying the specific gravity of the solution and the pressure of steam in the worm, any temperature from 220 degrees Fahrenheit to 340 degrees can be obtained in the bath. The canisters being deposited in the solution, sufficient heat is applied to them to bring them gently to the boiling point, and the steam is allowed to pass freely from thence, thus expelling the air at the proper time, (known only to him by experience, and depending, of course, upon the size of the tin and the nature of its contents), the operator closes the small hole by a seal of solder *while the steam is issuing.* To enable him to do this he holds a cold sponge in his hand, and immediately the seal is complete, he applies the sponge to condense the steam inside the tin, to enable the seal of solder to harden. The temperature of the bath is then raised, and the tins are boiled for a short time longer to decompose any small particles of air that may remain in the meat, which the steaming process has failed to pass away.*

* Or, according to the germ theory, to kill any residual germs which may have gained entrance during the moment of sealing.

Another method in use, especially among the Scotch preservers, is to boil the canisters, as in Appert's system, for a considerable period, and then to pierce a small hole and immediately close it again, for the purpose, as they say, of letting out the air; and again subjecting the canisters to a lengthened period of boiling. This is a very long process, and quite unadapted for this colony, where labour is dear, and time so great an object, when large masses of meat have to be operated upon in a limited period.

The number of men in the employ of the Melbourne Meat-Preserving Company is about 250, consisting of tinsmiths, slaughtermen, butchers, stockmen, cooks, preservers, carpenters, tallowmelters, coopers, lightermen, and general labourers. The wages paid by the company are about £400 weekly. The present consumption of animals is about 150 oxen and 4000 sheep per week. The former are being put up expressly for the English Admiralty, who have entered into large contracts with the company for the supply of preserved beef for use in the navy. The meats have gone also largely into consumption of the troops in the present war, and prior to its being invested by the Prussians no less than 2,000,000 lbs. of these meats were taken into Paris, for the use of the inhabitants during the siege. Since the foregoing was written the demand for Continental supply continues unabated.

LECTURE VI.

HOUSEHOLD CHEMISTRY.

DELIVERED BY GEORGE FOORD,

ON 17th NOVEMBER, 1870.

"HOUSEHOLD CHEMISTRY" is the subject of this evening's lecture.

Each one of this audience is doubtless aware that every tangible object has its chemistry, and that most operations included in the domestic economy can be looked at from a chemical point of view. You will understand that the chemistry of the household embraces a wide field of inquiry, and that it includes a multitude and great variety of objects. The scope is so large as to require for its consideration a course, rather than a single lecture; but as the series of lectures which we bring to a close this evening is intended as an introduction, only, to more detailed teaching, I propose that we now confine our attention to the chemical aspect of a few of those more prominent questions which especially concern the daily domestic experience.

Let us consider the air we breathe in our apartments; the water we drink; the food consumed; and the fuel employed, as a source of light and heat, by us. In truth, to pay even a passing attention to each of these subjects will require the utmost economy of the time at our disposal. To-night, in considering these topics, I address myself to Paterfamilias and to the mothers of Young Australia, with especial reference to the familiar concerns of the household. I intend that what I advance shall have a practical application of moment to each of us; and it will be my aim to speak clearly and concisely, taxing your patience as little as possible.

Let us commence, then, by paying a brief attention to the air of our apartments. In a former lecture I showed you that air consisted of a mechanical mixture of oxygen and

nitrogen gases; of about one measure of oxygen to four measures of nitrogen gas; and that besides these major constituents, there were also present in air small proportions of carbonic acid gas and aqueous vapour, and yet smaller proportions of certain other substances. I showed you that when charcoal or any other form of carbon is burnt in oxygen or air, carbonic acid gas is the product;—also, that this carbonic acid gas is, under the influence of sunlight, absorbed by the leaves of plants, which restore pure oxygen, derived from this carbonic acid, to the atmosphere; so that all the charcoal which we obtain from the trees of the forest, they have obtained from the atmospheric carbonic acid, in the way described. I showed you that the breathing of animals is of a distinctly different chemical nature to the breathing of plants;—during the breathing of animals there is a continuous appropriation of the atmospheric oxygen, and a constant outpouring of carbonic acid. I pointed out that plants and animals compensate each other's effects upon the composition of the atmosphere, the carbon in the carbonic acid expired by animals being appropriated by plants, and the oxygen set free on the decomposition of carbonic acid by plants being appropriated by animals; so that the normal proportions of nitrogen, oxygen, and carbonic acid are constantly maintained. I showed you how gases possess the remarkable property of diffusing into each other, irrespective of their specific gravities; —heavy gases expanding upwards to mix throughout light gases placed above them, and light gases descending down into heavy gases; so that there is a natural provision always at work, promoting an uniform composition of the atmosphere everywhere. I mentioned the average proportion of carbonic acid in the air as four parts in 10,000; and now I think that I can show you that these facts,—these simple facts of chemistry,—have very important bearings concerning the air of our apartments.

If all the openings of an apartment,—the windows, doors, and chimney,—be securely closed up, so as to stop all ventilation; and if a charcoal fire be lit in the room, the oxygen of the air is consumed, and a bulk of carbonic acid equal to the oxygen which disappears is generated. The resulting close atmosphere of nitrogen and carbonic acid gases is a narcotic poison, and it suffocates any one attempting to breathe it. Carbonic acid gas is, indeed, the choke-damp of the miner. We breathe the ordinary atmospheric air, containing four parts of carbonic acid in 10,000, throughout our lives; and

even when the proportion of carbonic acid rises somewhat above these figures, the air may be breathed with impunity. But, increasing the proportion, we soon arrive at the limit,—air containing more than one thousandth of its weight of carbonic acid, it is not advisable to breathe for any length of time. Air containing one two-hundredth of its bulk of carbonic acid brings languor and headache. A larger proportion produces insensibility, and when the proportion rises to one-twelfth it causes suffocation.

There is another compound of carbon and oxygen, called carbonic oxide. It contains, for a given weight of carbon, exactly half as much oxygen as carbonic acid. It is combustible, and may be burnt; taking a second dose of oxygen, and becoming carbonic acid. It is produced whenever carbon or one of its combustible compounds is burnt with limited access of air. Stoves with a feeble draught are often sources of this carbonic oxide, which is even more poisonous than carbonic acid.

The air issuing from the lungs of a man at each expiration contains from three and a half to four volumes of carbonic acid in one hundred volumes of air, and could not therefore be breathed again without danger. The total amount of carbonic acid evolved by the lungs and skin amounts to about 1200 cubic inches per hour. In order that it may be breathed again without inconvenience, this should be distributed through 140 cubic feet of fresh air, or a space measuring 5.2 feet each way. Hence the necessity for a constant supply of fresh air by ventilation, to dilute the carbonic acid to such an extent that it may cease to impede respiration. This becomes the more necessary where an additional quantity of carbonic acid is supplied by candles or gas lights. Two ordinary gas burners, each consuming three cubic feet of gas per hour, will produce as much carbonic acid as one man. Fortunately, a natural provision for ventilation exists in the circumstance that the processes of respiration and combustion, which contaminate the air, also raise its temperature, thus diminishing its specific gravity by expansion, and causing it to ascend and give place to fresh air. Hence the vitiated air always accumulates near the ceiling of an apartment, and it becomes necessary to afford it an outlet, by opening the upper sash of the window, since the window ventilates immediately only the lower part of the room.

Plants which, under the influence of sunlight, absorb carbonic acid and expire oxygen, behave in a very different way

during the night; then they absorb oxygen and exhale carbonic acid. The extent to which they do this is small, however, as compared to their power of decomposing carbonic acid during the day. But a knowledge of the fact should put us on our guard against making green-houses and flower-shows of our bed-rooms. From these facts we may quite safely conclude that capacious sleeping apartments are conducive to health, and that ample ventilation is of vital importance, not only the ventilation afforded by the fire-place, but also openings near the ceiling, so as to effect a continuous change of the whole air of the room.

The question of the best part of a room to introduce fresh air has received much attention. It has been considered by the Commissioners for improving the sanatory condition of barracks and hospitals, who have recommended that all inlets of air should be placed close to the ceiling, in every room that has an open fire-place. The air is to be admitted through perforated bricks, allowing one square inch of ventilating opening for every 60 cubic feet of contents of room; but half that inlet area is deemed sufficient if air from without is warmed by passing round the back of the fire-grate. The air passes into the room at the cornice line, the back of the cornice is sloped upwards at an angle of 45 degrees, and deflects the inward current against the ceiling. It escapes into the apartment through a perforated zinc diaphragm, and the current, moving against the ceiling surface, sets the whole air of the room in gentle but effective circulation. A plan involving these principles, but somewhat different in detail, has been recently put in practice by Mr. Lloyd Tayler, architect, who, at my request, has furnished me with a written note respecting it. He perforates the walls all round the apartment; the air bricks and perforated zinc are both placed in the thickness of the wall itself, and there is an inch free space above the cornice all round the room, through which space the air passes up and on to the ceiling surface. Mr. Tayler also mentions a distributive system of thin boxes traversing the ceilings, and forming beams, thus dividing the ceiling into compartments, and securing a current of air at times, when, owing to the disposition of the premises and the movement of the external air, these, with the simpler arrangement, would be unfavourable to an effective ventilation. Speaking of this method of ventilation, Mr. Tayler states that he has found in practice that the thin stream of air is so effective at the ceiling line, although quite imperceptible elsewhere,

that the workmen engaged in finishing the ceilings have stopped up the air grates to avoid the draught.

Passing from the consideration of air vitiated with carbonic acid, I have a few words to say concerning two other minor constituents. When we burn coal, the sulphur of the iron pyrites in the coal is burnt with formation of sulphurous acid. When we burn gas in our apartments a portion of the sulphur of the coal, which inevitably remains in the gas, is burnt, also forming sulphurous acid. This sulphurous acid is an irritating, suffocating compound, and when coal-gas has been kept continually burning in an apartment, its destructive effects upon our chattels may become obvious enough. At the library of the London Athenæum Club, the destruction of the bindings of the books was traced to this cause, and Faraday, to obviate this result for the future, contrived an elegant method of ventilating the gas-lights, so as to carry off all the products of combustion. Faraday's gas bracket is formed of two concentric tubes, the gas-burner is covered with a double chimney, and the top of the outer chimney is closed by a thin disc of mica. The air of the apartment passes upwards through and around the argand burner, and the products of combustion closed in by the mica disc return downwards between the cylindrical glasses, and escape through the interspace between the concentric metallic tubes of the gas bracket. But sulphurous acid in feeble proportion is not in every case an objectionable constituent of air. It is antiseptic, and the comparative immunity of large cities, where coal is the fuel in use, has been ascribed to the sulphurous acid continually poured into the air.

Before quitting this part of our subject, I must say a few words concerning another constituent of the air we breathe,—concerning what have been called miasmata and malarias, those subtle constituents of unwholesome air,—organic poisons, more or less disseminated through the atmosphere in certain positions, and to which is attributed the dissemination of fevers and diseases of that class. Miasmata appear most prevalent at low levels; they hover over swampy grounds, and would seem to gravitate as though composed of solid particles. In several particulars they have close points of resemblance with the atmospheric spores and germs of which I have already spoken. Sir Humphry Davy, in his "Consolations in Travel," asserts that the line of malaria above the Pontine marshes is marked by a dense fog, morning and evening, and that most of the old Roman towns were placed upon eminences out of reach of this fog. Whatever the nature of this miasma, it is certain that

marshes and swamps are by no means the only sources; the mud left on the drying-up of ponds or lakes, and neglected sewers and drains, are capable of producing the subtle poison. This statement indicates the precautions for avoiding these emanations:—

Do not choose your residence in hollows, at low levels, near swamps or marshes, or open drains.

Allow no animal or vegetable refuse to lay about.

Let nothing stand in your drains.

Avoid rotten foundations of wood, and keep all dry.

In this country we are but little troubled with exhalations from chemical works,—with muriatic acid gas poured by hundreds of tons into the atmosphere, as in Lancashire, or with a cloud of sulphurous smoke, as that of the Swansea copper works, which is sometimes visible at twenty-seven miles distance. On the other hand, the factories where animal produce is treated have already made themselves felt, and the effects upon the public health of the odours dispersed from these establishments has already engaged attention. It would be out of place to discuss this large question on the present occasion. I have, however, two remarks to make:—

Any one really interested in this question, and taking pains to inquire into the facts, will be greatly struck by the general healthfulness of the workmen employed in the factories referred to,—in the fellmongering and boiling-down factories, and similar works. This, as far as it will bear rigid statistical inquiry, is so far in favour of the healthfulness of the several pursuits; but we must remember that these employments are in the fullest sense selective; the sickly and qualmish are repulsed by the nature of the occupation, while of the robust who present themselves for employment, the manufacturer naturally selects those of the best physique.

It does not follow that the most ill-smelling air is the most unwholesome; that of a mangrove swamp may be deadly; the air of the glue-maker's yard may be merely nauseous; and another thing to remember is that *deodourising* and *disinfecting* are quite distinct operations. William Crookes, when employed on the cattle-plague question, put this in a very clear light. He found that tainted meat was deodourised by chloride of lime much more quickly than with carbolic acid; but he also found that, after a few days, that immersed in carbolic acid water had lost all odour, and had dried up completely, while the piece treated with chloride of lime had resumed the putrefactive state.

Let us now pay a little attention to drinking-water. I need not enumerate the sources from which we obtain it. Of course there are some extreme cases in which rain water may be vitiated;—where much arsenical fume from roasting furnaces is poured into the air, such a thing might happen, but such possibilities are so remote that I need not further allude to them. Rain water as it falls is generally nearly pure water; it is as soft as distilled water, and although not always as sparkling and palatable as some spring waters, it is unexceptionable for domestic use,—for washing, and for most, if not all, other purposes. It is, however, the easiest thing in the world to contaminate rain water and render it positively harmful. It has a remarkably rapid action on lead, and when there is much lead flashing and guttering on the roof from which it is stored, it is well to make sure that no lead contamination has taken place. Rain water which has passed over surfaces painted with white lead is especially suspicious; very serious results have followed the drinking of water collected from roofs of cottages covered with painted tin plates. The oil of the paint is soon perished by the sun, and then the white lead is washed down into the water butt; and whenever the water is taken out after rain and before the turbid water has had time to become clear by subsidence, a dose of lead poison is almost certain to be dealt out to the family. A drop of sulphuretted hydrogen water produces in lead-contaminated water either a brown tinge or a brownish black precipitate, according to the quantity of lead present. Faraday considered the subject of contaminated water as it applied to the lighthouse keepers, who trust to the water collected from the lead cap of the lighthouse lantern. He found that if the lead-contaminated water be shaken with whiting and allowed to settle, all the lead is separated, and the water is rendered safe for drinking. Rain water stored in underground tanks is liable to contamination from leakage or infiltration; as a rule, if such water has acquired an unpleasant taste or odour, it should not be used for drinking, certainly not without previous boiling.

Brackish waters are known by their effect on nitrate of silver, with which they throw down a curdy precipitate; of course their utility is influenced by the quantity of salt contained in them. If the usual sea-water compounds are the only salts present, a slight brackishness is not objectionable, in the same sense as the organic impurities derived from drainage.

Aluminous waters,—waters containing sulphate of alumina, are certainly objectionable; they are liable to disorder the digestive organs, just as bread containing alum is reputed to do. Chalybeate waters, waters containing iron salts, assume an inky colour when in contact with astringent substances; much of the water on our diggings becomes charged with iron salts derived from the decay of the pyrites of the schistose rocks; the gum leaves falling into such water tinge it of a dark purple. Although iron rust is harmless, these styptic waters are unfit for culinary purposes.

Water containing calcareous salts, as bi-carbonate of lime, or containing bi-carbonate of magnesia, or of iron protoxide, produce a precipitate on boiling; the furring of vessels in which the water is boiled arises from this cause. Waters mineralized with bi-carbonate of lime, gypsum, and some other salts, are, as a class, what are called *hard waters;* always distinguishable by their curdling effect upon soap. The economic bearings of this question of the relative hardness of different waters may be indicated by an example: with 10,000 gallons of the water supplied to the city of Lancaster the loss of soap by this curdling action would be one pound weight, while with the same quantity of Thames water one hundredweight of soap would be wasted. In speaking of hard and soft waters, an unqualified preference is almost invariably given to the softest kinds; but there are probably two sides to the question; the mineral constituents, as found in many mineral waters, the bi-carbonates, for example, may be not without their uses in the animal economy. While it is admitted that what are called mineral waters are of so much efficacy in restoring health, it is at least feasible that the purer ordinary spring waters, sparingly mineralized, may confer some especial benefit upon the healthful subject.

Waters containing sulphates, and kept in wooden vessels, especially if confined, as casks of Thames water are bunged down for ship's use, soon become fetid, an action of decomposition taking place between the wood and the sulphates; boiling or exposure restores such water to a sweet condition.

If I were asked for general rules for potable water for the household, I should say;—collect, if possible, from a slate roof, into cast iron gutters. Avoid white lead. Store in the cubical iron tanks. Cover the water effectually from the daylight, so as to disfavour the growth of the various forms of aquatic life,—mosquitoes especially. Iron rust is the least objectionable of all impurities. I would also add that whenever there is any cause for apprehension concerning the salubrity of a

drinking water, consult a capable chemist on the main question. Do not seek a complete analysis, for that is seldom required; but get the water examined just so far as will tell you whether you may safely drink it or not.

Now, we come to a few considerations concerning food. I trust the time is not far distant when an extensive collection of foods, accompanied by tables of their composition and relative values, will be displayed in the Museum of this Institution. I trust that this will be the case, because the teaching afforded by such a series would be of a far more satisfactory nature than mere statements, apart from the illustrations. What I have now to remark must of necessity be limited to the general question.

Of foods common salt stands alone; not that it is the only mineral constituent of the animal economy, for if we incinerate a little wheat or flesh, we obtain a mineral residue or ash, in each instance containing several constituents distinct from common salt. But common salt is the only mineral substance necessary to the system, and consumed in its purely mineral state.

Of ordinary food substances, the proximate constituents have been divided into *force* producers, and *flesh and force* producers. The one kind produces force or energy only;—the other, besides producing force, also assists in building up animal structure, and especially flesh. The limitation of our time prevents the giving anything beyond the barest outline of this interesting subject. Professor Frankland tells us:—"Not only does food supply the daily waste of the human body, but, as the body increases in size from birth to adult age, it is supplied with materials for this increase by the aid of food. In order, therefore, to understand the value of food from its composition, it is necessary to know the composition of the human body. Just as any other compound substance can be submitted to chemical analysis, and the elements of which it consists ascertained, so can the composition of the human body be discovered. Such analyses of course become difficult in proportion to the complication of the body analyzed, and only an approach to the true quantities in which the elements exist can be expected. The results of such an analysis have been attempted, and the quantities of each element entering into the composition of a human body, weighing 11 stones, or 154 pounds, are (as far as possible) presented to the eye." For presenting the results of this analysis, Professor Frankland gives this

TABLE OF THE ULTIMATE ELEMENTS OF THE HUMAN BODY.

	LBS.	OZS.	GRS.
Oxygen	111	0	0
Hydrogen	15	0	0
Carbon	21	0	0
Nitrogen	3	9	0
Phosphorus	1	12	190
Calcium	2	0	0
Sulphur	0	2	219
Fluorine	0	2	0
Chlorine	0	2	382
Sodium	0	2	216
Iron	0	0	100
Potassium	0	0	290
Magnesium	0	0	12
Silicon	0	0	2
Total ... ... Lbs.	154	0	0

"Other elements," says Dr. Frankland, "have been found in the body, as copper and manganese, but these are probably accidental." He goes on to say, "These elements when combined together form a set of proximate principles, out of which the tissues and fluids of the body are formed." Here is the computation of the proportions of these proximate principles into which the foregoing elements are built up:—

	LBS.	OZS.	GRS.
Water	111	0	0
Gelatin	15	0	0
Fat	12	0	0
Phosphate of Lime of the bones, teeth, &c.	5	13	0
Carbonate of Lime	1	0	0
Albumin	4	3	0
Fibrin	4	4	0
Fluoride of Calcium of the bones and teeth	0	3	0
Chloride of Sodium	0	3	376
Sulphate of Soda	0	1	170
Carbonate of Soda	0	1	72
Phosphate of Soda	0	0	400
Sulphate of Potash	0	0	400
Peroxide of Iron	0	0	150
Phosphate of Potash	0	0	100
Phosphate of Magnesia	0	0	75
Silica	0	0	3
Total ... ... Lbs.	154	0	0

These compounds, in passing away from the body, form many others, which may be here left out of consideration, as not forming a necessary part of the fabric of the human body.

In ordinary foods, those combinations which are free from nitrogen are generally classed as *force* producers; their consumption in the animal system may be compared to that of fuel under the boiler of a steam-engine, with evolution of heat, and giving rise to mechanical motion or work. A very clear elucidation of this point was given in Professor Wilson's lecture on the "Conservation of Energy." The fat of the animal system is so much of these force producers stored up,—a bank credit, which may be at any time consumed, when food from without is diminished below the requisite amount.

The *flesh and force* producers, rich in nitrogen, go to build the muscles, &c.; and the consumption of the substance of these muscles, which is always going on, is, of course, attended with elimination of muscular force. To the consumption of muscle, and of the nitrogenous foods forming it, is chiefly attributed the manifestation of muscular force, or the operations of life. To the consumption of the animal fat,—of the fatty saccharine and starchy foods from which it is built, the development of animal heat is chiefly attributed: they are regarded as fuel, keeping up the temperature of the body. It is proper, however, to state that these chemico-physiological questions are highly complex, their investigation is of a most difficult nature, and we are very much in the dark concerning a large part of this important subject. It cannot be asserted that foods such as starch or sugar play no part in the production of muscular motion or work; there is indeed reason for believing to the contrary; nor is it probable that the using up of muscular fibre is wholly unaccompanied by the development of heat; but as mere starch and sugar cannot build muscle, the distinction of force producers and flesh formers is a valid one.

As affording the means of comparison of the analysis of the constituents of the human body with those of the several foods, enabling us to see at a glance which of the latter can enter into the essential architecture of the system,—which can enter into the formation of muscle, nerve, and bone, the distinction, recognised in a properly qualified sense, is an useful one. Of course the blood is the distributer of these food materials, and the high road by which the waste is carried off; it is the vehicle of the gases taken in at the breathing surfaces, and which conduce to these changes. In the air expired from the lungs, carbonic acid is exhaled, just as the same gas is poured

out from the chimney of a boiler furnace. Under the boiler, let us say, we burn wood; in the animal system instead of the cellulose and resin of the wood, it is starch, or sugar, or fat, that is consumed, and the carbon of these bodies in each instance escapes as carbonic acid gas.

Different foods may be easily compared according to this distinction of flesh and force producers, and force producers only. Thus, milk of the cow consists of—

Water......... 86 parts.		
Casein........ 5 „	The casein is the flesh and force producer	5 parts.
Butter......... 3·5 „		
Sugar of milk 4·5 „	The butter and sugar of milk are the force producers	8 „
Salts .... 1 „		
In 100 parts.		

Maize contains—

Water......... 14 parts.		
Gluten ...... 12 „	FLESH AND FORCE PRODUCERS.	
Starch ...... 60 „	The gluten	12 parts.
Sugar & gum 0·3 „	FORCE PRODUCERS.	
Fat............ 7·7 „	The starch, sugar, gum, fat, and fibre, or cellulose ...	73 „
Fibre .... 5 „		
Mineral matter 1 „		
In 100 parts.		

In 100 parts of wheat, the flesh and force producers form .... 14·6 parts.
The force producers .... 69·8 „

In 100 parts of beef, the flesh and force producers form .... 15·0 „
The force producers .... 30·0 „

The computation of the value of different kinds of food is reduced by these and similar analyses to a mere matter of figures.

Concerning the adulteration of food I wish to add a few words, although I am free to confess that this interesting subject has of late years grown to dimensions very far beyond our present limits. What I have to say may be accepted as a mere example.

The margin between fraudulent adulteration and permissible admixture of extraneous materials is a very delicate boundary-line. The adjustment of supply and demand presses with irresistible force upon the producer whenever the raw material or natural product falls short, and man's ingenuity is then taxed, nay, strained, to make up the deficiency. Of course it would be unreasonable to expect the ingenious manufacturer to give up his own particular secrets to his rivals in trade; and from these and other causes it results that a very large range of the materials consumed in the household are not altogether what they are represented to be. Mustard is not simply bruised mustard seed. Coffee is a mere mixture of ground coffee with other materials. Wines are compounded, some of them with elder juice, molasses, and grain spirit; and in short, as Accum expressed the case forty years ago, "there is nothing genuine but matches (the old brimstone ones) and slate pencil." When we buy broad cloth, we know that it is not all long staple wool; and we know that the admixture of shoddy is a necessity coming out of the demand for woollen fabrics having become greatly in excess of the supply of raw wool. We get as good a material as we can, and when dealing with respectable tradesmen, we obtain, I suppose, fair value for our money. It can hardly be said that we are defrauded by this admixture of shoddy and mungo, which McCulloch, in his *Dictionary of Commerce*, has described as "one of the greatest triumphs of art and manufacture."

As I have said, the question of fraudulent adulteration is a very difficult one to decide upon; with deference to other opinions, I beg to express, in general terms, my own views on the subject. Where deceit is intended and practised, there fraud commences. Whenever the addition cheats the judgment of the purchaser, imposing on his confidence by misrepresentation, all such cases are fraudulent. An adulteration may be doubly dishonest; it may attack our pockets and destroy our health. When pepper is adulterated with rice flour, it is rendered less pungent, but not less wholesome; our pockets only are attacked by this addition. But when vinegar is fortified with oil of vitriol, when red lead, ochre, bole, emerald green, verdigris, chrome yellow, vermilion, nux vomica, cocculus indicus, and similar poisons, are added to food materials, our health is attacked as well as our pocket; a double trespass is committed, and a double penalty ought to be paid whenever detection of this kind of fraud is brought home.

The question of adulteration appears to be intimately con-

nected with that of "brands" and trade marks. Let the manufacturer be well protected from piracy of his trade mark, and this will encourage him to do all in his power to uphold the prestige which it affords. With trade marks well protected, we have an additional power for hunting down the fraudulent manufacturer. Let the work of the Corporation analytical chemist be directed rather to exhaustive reports on the goods put into the market under the several brands, than to petty prosecutions of small tradesmen;—let the remuneration be such as will command the talent and character necessary for the work; and then the manufacturer, alive to his own interest, will take care to supply goods such as will bear a strict investigation. The householder cannot afford to go to the chemist for analyses of the stores in his pantry, but it would be greatly to his profit to pay his share toward efficient municipal action in the direction indicated. The arts of adulteration and sophistication have been, unfortunately, so intimately woven in with manufacturing pursuits, that it would be too sanguine to expect that any means, however searching and energetic, can at once completely eradicate the evil. But it would be a great thing to repress it as much as possible; and if I am correct in my views, the direction which I have pointed out is the road which, steadily persevered in, would lead to valuable results.

Respecting poisonous materials, liable to be consumed as food, I have not time to speak; it also is a subject which might well be taken for a course of lectures. Mr. Tulk, our librarian, has brought us a book in which the edible and poisonous fungi are distinguished: this is open to the inspection of those members of this audience who are interested in the subject. A series of drawings of poisonous plants, and copies of these drawings of fungi, distinguishing the edible and the poisonous kinds, would form useful illustrations in the food series of the Technological Museum.

Liebig adduces curious instances of poisonous food. He tells of a hart caught in a snare, so that it was tortured and frightened during a lingering death; he narrates that those who partook of the flesh of this creature were poisoned, and that one of them died in consequence. Liebig also mentions a particular kind of decay taking place in sausages, and which is communicated to the blood of persons partaking of them, with fearful consequences; they fall to pieces joint by joint. We all know that fish food is poisonous under certain circumstances; and uncooked food, or food im-

perfectly cooked, may produce disease from the lodgment of entozoic life into the systems of those consuming it. This is instanced in Trichina, sometimes observed in low-class swine's flesh as little white knots in the fibre of the meat. Under the microscope each of these knots is seen to be a lemon-shaped sac, containing coiled within it two minute worm-shaped animals, the history of whose transformations is more curious than appetising.

From these remarks concerning food, let us pass to a few concluding observations respecting fuel, the sources of heat and light, employed in the household.

The best practical test of the relative value of fuels, as a source of heat, is that afforded by the quantity of water which a given weight of each kind will raise to a certain temperature, or evaporate into steam. The ash of fuel is of course mere dead weight; of no value. For all practical purposes it may be stated that the amount of heat generated by the combustion of a given weight of fuel depends on the weight of carbon and hydrogen, respectively, which enter into combination with the oxygen of the air, during the combustion of the fuel. One grain of carbon, as it exists in charcoal, when perfectly burnt, will raise 8080 grains of water 1 degree Centigrade. In the same way, 1 grain of hydrogen, when burnt, will raise 34,400 grains of water 1° C. The hydrogen evolves about 4½ times as much available heat as its own weight of carbon.

The relative calorific value of different fuels has been estimated—

For Oak	at	...	...	4212
„ Peat	„	...	...	5656
„ Lignite	„	...	...	6569
„ Bituminous Coal	„	...	...	7544
„ Charcoal	„	...	...	8003
„ Anthracite	„	...	...	8337
„ Coke	„	...	...	8009

The weight of water at 100° C. converted into steam—

For one part	Hydrogen is	62·658
„	Coal from Newcastle, England	14·945
„	Carbon	14·691
„	Peat, kiln dried	10·254
„	Wood, dried at 140° C....	8·100

For employing coal gas as fuel, various thoroughly efficient contrivances are now obtainable. We can heat our apartments

with gas stoves,—we can warm water for the bathroom,—we can bake, broil, and boil our food, by means of gas. High temperatures are obtainable by the combustion of coal gas, as instanced in its use by the silversmiths and coppersmiths for hard soldering. Gold, and even cast iron, can be easily melted in pretty large quantities by employing gas as the only fuel. But when we employ coal gas as a source of heat, the mode of using it is very different to that which should be employed when we use it for illumination. For heating, the coal gas, issuing from the jet, should be mixed with a regulated supply of air; so as to secure the immediate and complete combustion of its carbon, as well as its hydrogen. The common laboratory burner, as contrived by Bunsen, will make this point clear. The gas burnt in the ordinary way in a common burner emits white light, and will deposit soot on the vessel which we wish to heat; but in the Bunsen burner, at the base of the metal tube through which the gas issues there are closed air-ways, and if we open them, then the entering air mixes with the coal gas, and the mixture of air and gas, burning at the top of the tube with a pale bluish flame, emits little light, but a maximum of heat. Its flame is like that of spirits of wine, and may be applied to a variety of purposes for which heat is required. Of course gas is not as cheap a source of heat as coal or other solid fuels, but when the convenience of gas is considered,—the fact that we have only to turn a tap to obtain our supply;—when the value of our time is taken into account, it will often be found a great advantage to use gas as fuel, and it seems strange that gas stoves have not come into more general use. In the summer time, in this climate, for cooking purposes gas will be found a great convenience, and there are cases in which the value of gas-heating apparatus can be hardly over-estimated. A few Bunsen burners, heating a light copper drum, fixed in a bathroom, enables us to obtain water for a hot bath, at any time, in a few minutes. A domestic want in case of sudden illness (often a very urgent one) is thus satisfied by a very simple provision, at a very moderate outlay.

Concerning gas an as illuminant, a few remarks will be well in place at this point. Gas, properly fitted, is the safest of all means of obtaining artificial light. Of course it is possible to have accidents with gas, but these accidents must arise from either defective fittings on the one hand, or from carelessness on the other. Gas allowed to escape may accumulate until it forms

with the air an explosive mixture; and then a light brought into it will cause a violent explosion and often serious results. It is fortunate that coal gas is not altogether devoid of odour; a very slight escape of unburnt gas is easily detected by the smell, and thus waste and danger are alike obviated. The safety of gas depends on the permanence of the size and position of the flame, and on its freedom from sparks: we leave the apartment in which a gas flame is burning with perfect confidence, and, returning to it after hours, we find the flame just as we left it. Not so with lamps and candles; candles burn down in the sockets, or they may even fall over on one side; and even oil and other lamps cannot be left alone with the same confidence as that placed in gas burners. In burning gas there are two points of especial interest to the consumer. The first refers to the amount of light obtained from the gas when properly burnt. Gas of average quality should have a value of fifteen candles, that is to say, when burnt in a proper argand burner, at the rate of five feet per hour, the light emitted should be equal to that of fifteen spermaceti candles, each consuming 120 grains of spermaceti per hour. Another point concerns the burners to be employed. It has been ascertained that at some of the London newspaper printing offices, where economy of gas light is a matter of great moment, not more than one half of the obtainable light is obtained from the gas consumed, and this bad economy has been clearly shown to arise from the employment of burners of an unsuitable pattern. The best pattern of argand burner is that of Sugg; but I may mention, as a general rule, that in order to obtain the most light from a given amount of gas, it is necessary to burn it at a low pressure. It should issue from the burner into the atmosphere with so little force as to be almost inclined to smoke. Burners with large apertures, or burners in which the exit of the gas is choked by a perforated diaphragm in their interior, are favourable to the economy of the gas. When the utmost economy of gas is attained the flame is somewhat inclined to flicker, and, in fact, the best practical result is attained when we fall a little short of extreme economy of consumption,—when, in fact, we have as economical a flame as it is possible to obtain without unsteadiness.

The more common kinds of candles include the tallow candle, soft and unctuous, burning with a reddish light, and when blown out emitting a nauseous acrid odour from the smouldering wick. This odour arises from a volatile principle

called acrolein; it is derived from the glycerin of the tallow. All natural fats contain glycerin as one of their proper constituents, and all candles made of fats containing this glycerin emit acrolein when extinguished so as to leave the snuff burning. In candles of stearic acid,—stearine candles as they are commonly called,—the glycerin is absent; the fat has been decomposed, the glycerin and fluid fatty acids have been separated; the solid stearic acid forms the substance of the candles. The smouldering wick of the stearic acid candle emits no smell of acrolein, and, in short, this candle is in every sense superior to that in which mere tallow, or any mixture containing tallow is employed. The material of the paraffin candle is a pure, solid hydrocarbon, one of the many constituents of the oil of schist. These candles are as elegant as spermaceti, they give a beautiful light, and, considering their great beauty and general good qualities, they are cheap at their price. But like some other beauties, they have, I fear, one defect,—one serious defect, which makes itself especially apparent in the summer months. On a hot day they soften with the heat so as to bend out of the vertical line. One of these candles may even bow right over, with the risk of setting fire to the neighbouring objects. In the climate of Melbourne, it would, I fear, be dangerous to use these elegant candles during the hot weather.

Fuel leads us to a few remarks concerning matches. Most kinds of matches, but not all, contain common phosphorus. It is well to remember that phosphorus is a virulent poison; the bright colour of the inflammable composition,—always an attraction to young children, makes this point all the more noteworthy. Matches are dangerous. If it were not for their very great convenience, the danger attending the employment of matches would long since have put them out of use. A whole box of them may be, at any time, ignited by mice gnawing them, for the glue contained in the combustible composition with which they are tipped; or the lid of a match box carelessly shut down may readily ignite the contents. The destruction of property attributable to the use of these matches, from first to last, must have been immense. Nor is property the only loss, for a sacrifice of life attends not only the casualties produced by the accidental ignition of these lucifer matches, but belongs also to the very manufacture of the matches themselves. Disease of the jaw-bone is the dreadful wages of the manufacturer of phosphorus matches. Evidence collected on

this subject has shown that out of 59 patients who suffered from this disease, 36 were mixers and grinders; operations which expose the workers to the phosphoric fumes. Of the 59 patients no less than 21 died, and the others were more or less disfigured by the partial or total obliteration of either the upper or lower jaw, or in some cases of both; while the poor sufferers in many cases were not restored for years. Latterly there has appeared a way out of this dreadful difficulty; the matches are made with a deflagrating mixture, free from phosphorus, and the striking surface of the match box is prepared with a layer of *amorphous* phosphorus, which is *quite safe to the workmen preparing it*, and *to the household employing it;* but on which, when struck, a small portion of the amorphous phosphorus is by the friction converted into common phosphorus, which ignites the match. These matches are unexceptional for domestic use, and an additional reason for preferring them is afforded by the conviction that we wash our hands of the slow murder of the poor phosphorus-match maker.

The danger attending the use of phosphorus matches leads me to say a few final words concerning spontaneous combustion, and those obscure causes of fires which are so often included under this name. You know, when a fire takes place in the hold of a ship, in a railway truck, or in the warehouse, how often it is traced to bales of cotton or wool, or to bundles of bark, or to some other *fibrous* material, pretty tightly packed, but not so tightly as altogether to exclude the air. The material is understood to have been packed damp, and to have heated until it has burst into flame. Now, I wish to point out what takes place when a piece of wood is painted with oil colour. In a few hours we find that the oil has dried,—the oil having undergone a chemical change, and from a fluid becoming a hard substance. This drying of oils is a process of oxidation,—the oil combines with oxygen of the atmosphere, becoming a solid resin. During the process, which is a kind of slow combustion, heat is given out, but we do not notice this heat, because the thin film of paint is spread out and exposed to so large a bulk of atmospheric air. But if the same kind of change takes place in a limited atmosphere, the result is very different. The fibre of a bale of wool or cotton presents altogether an immense surface; the air between these fibres, packed in the bale, is limited in amount, and is locked in so that it cannot freely circulate. If owing to the presence of moisture or grease, or both, oxidation takes

place, heat will be generated,—the temperature rises because there is no quick ventilation in the compressed mass,—and, sooner or later, the whole may burst into flame. It is easy to produce this kind of result by way of experiment. If a roll of calico be oiled with linseed oil, and rolled up, it will soon heat, and in a few hours on partially unrolling it, so as to assist the result by a little additional air, it will suddenly burst into flame. A simple lecture-table experiment will afford an illustration of these spontaneous ignitions. Common phosphorus exposed to air undergoes slow combustion, but does not burst into flame unless handled, or subjected to friction. But if a solution of phosphorus in bi-sulphide of carbon be poured on to filtering paper, the solvent evaporates, and the phosphorus is left in so porous a state, exposing so much surface, that its oxidation is accelerated, the local heat rises, until the phosphorus spontaneously inflames. The teaching suggested by these facts is that in the household it is dangerous to put away greasy rags; the only safe thing to do with them is to burn them at once, and so get rid of them. Combustible materials of a fibrous nature are always rather dangerous, especially when packed away in quantity, in a damp state; for there is not only this chance of spontaneous combustion, but should they heat and inflame, their finely-divided state renders their combustion so fierce and rapid that it is almost impossible to extinguish them.

In closing this, the last lecture of our introductory series;—in taking leave, I ask permission to say, with as little egotism as possible, a few words concerning the performance of the work apportioned by the trustees to myself. I wish to say that although it has been gratifying to me to participate in this new and promising educational movement, I have from the first commencement to this hour felt the responsibility of the undertaking, and have experienced personal misgivings on that account. But that these misgivings have been in one sense counteracted by the continuous encouragement of well-filled benches and a hearty reception, I must also frankly admit. I cannot retire without thanking this and former audiences for the interest and sustained attention exhibited from first to last. A lukewarm attention would have added to my discomposure and would have increased my hesitancy; but your earnestness has proved throughout a strong support, which if it has not perfectly dispelled all doubts and misgivings, has at least made the task, sympathetically, a pleasant one.

TABLE OF THE ELEMENTS,

THE SYMBOLS BY WHICH THEY ARE REPRESENTED, AND THEIR EQUIVALENTS.

[OLD NOTATION.]

Name.	Symbols.	Combining Equivalent.	Name.	Symbols.	Combining Equivalent.
Aluminium	Al	13·75	Molybdenum	Mo	48
Antimony (Stibium)	Sb	122	Nickel	Ni	29·5
Arsenic	As	75	Niobium	Nb	
Barium	Ba	68·5	*Nitrogen	N	14
Bismuth	Bi	210	Norium	No	
Boron	B	11	Osmium	Os	99·41
Bromine	Br	80	*Oxygen	O	8
Cadmium	Cd	56	Palladium	Pd	53·24
Cæsium	Cs	133	*Phosphorus	P	31
*Calcium	Ca	20	Platinum	Pt	98·56
*Carbon	C	6	*Potassium (Kalium)	K	39·1
*Chlorine	Cl	35·5	Rhodium	Rh	52·16
Cerium	Ce	46	†Rubidium	Rb	85·4
Chromium	Cr	26·25	Ruthenium	Ru	52·11
Cobalt	Co	29·5	Selenium	Se	39·75
†Copper (Cuprum)	Cu	31·75	Silver (Argentum)	Ag	108
Didymium	D	48	*Silicon	Si	14
Erbium	E		*Sodium (Natrium)	Na	23
†Fluorine	F	19	Strontium	Sr	43·75
Glucinum	Gl	6·9	*Sulphur	S	16
Gold (Aurum)	Au	196·7	Tantalum	Ta	182
*Hydrogen	H	1	Tellurium	Te	64·5
Indium	In	37	Thallium	Tl	204
†Iodine	I	127	Thorium	Th	115·72
Iridium	Ir	98·56	Tin (Stannum)	Sn	59
*Iron	Fe	28	Titanium	Ti	25
Lanthanum	La	46·4	Tungsten (Wolframium)	W	92
†Lead	Pb	103·5	Uranium	U	60
†Lithium	Li	7	Vanadium	V	137
*Magnesium	Mg	12	Yttrium	Y	
†Manganese	Mn	27·5	Zinc	Zn	32·75
Mercury (Hydrargyrum)	Hg	100	Zirconium	Zr	89·6

NOTE.—The elements occurring in the Animal and Vegetable Kingdoms are marked—those of most frequent occurrence with an *, those of rare or sparing occurrence by a †.

INDUSTRIAL AND TECHNOLOGICAL MUSEUM.

CARDS OF INSTRUCTION.—No. 1.

CHEMISTRY.

In the following table are given the 65 elementary bodies—50 metallic and 15 non-metallic—which, either singly or in combination, form all substances; together with their symbols, forming the shorthand of Chemistry, and also the combining weights. The more frequently occurring metals are given in capitals, non-metallics in italic capitals, and the rarer bodies in small letter.

[NEW NOTATION.]

Name.	Symbols.	Weights.	Name.	Symbols.	Weights.
ALUMINIUM	Al	27·4	NICKEL	Ni	58·7
ANTIMONY	Sb	122	Niobium	Nb	94
ARSENIC	As	75	*NITROGEN*	N	14
BARIUM	Ba	137	Norium	No	x
BISMUTH	Bi	210	Osmium	Os	199·2
BORON	B	11	*OXYGEN*	O	16
BROMINE	Br	80	Palladium	Pd	106·6
Cadmium	Cd	112	*PHOSPHORUS*	P	31
Caesium	Cs	133	PLATINUM	Pt	197·5
CALCIUM	Ca	40	POTASSIUM	K	39·1
CARBON	C	12	Rhodium	Rh	104·4
Cerium	Ce	92	Rubidium	Rb	85·4
CHLORINE	Cl	35·5	Ruthenium	Ru	104·4
CHROMIUM	Cr	52·2	*SELENIUM*	Se	79·5
COBALT	Co	58·7	SILVER	Ag	108
COPPER	Cu	63·5	*SILICON*	Si	28
Didymium	D	95	SODIUM	Na	23
Erbium	E	112·6	STRONTIUM	Sr	87·5
FLUORINE	F	19	*SULPHUR*	S	32
Glucinium	Gl	9·3	Tantalum	Ta	182
GOLD	Au	197	*TELLURIUM*	Te	128
HYDROGEN	H	1	Terbium	Ter	x
Indium	In	37·8	Thallium	Tl	204
IODINE	I	127	Thorium	Th	115·7
Iridium	Ir	198	TIN	Sn	118
IRON	Fe	56	Titanium	Ti	50
Lanthanum	La	92	Tungsten	W	184
LEAD	Pb	207	Uranium	U	120
Lithium	Li	7	Vanadium	V	51·3
MAGNESIUM	Mg	24	Yttrium	Y	61·6
MANGANESE	Mn	55	ZINC	Zn	65·2
MERCURY	Hg	200	Zirconium	Zr	89·6
Molybdenum	Mo	96			

The above is a copy of the card alluded to by Mr. Foord, page 90.

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